1999 Proceedings

ILLINOIS CROP PROTECTION TECHNOLOGY CONFERENCE

January 6–7, 1999

SERVING AGRICULTURE AND THE ENVIRONMENT

University of Illinois at Urbana-Champaign
College of Agricultural, Consumer and Environmental Sciences
University of Illinois Extension
in cooperation with the
Illinois Natural History Survey
and the Office of Continuing Education
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1999 ILLINOIS CROP PROTECTION TECHNOLOGY CONFERENCE

The Illinois Crop Protection Technology Conference is an educational program sponsored by the following organizations:

University of Illinois Extension
College of Agricultural, Consumer and Environmental Sciences
University of Illinois at Urbana-Champaign

Illinois Natural History Survey

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PROGRAM • JANUARY 6 & 7, 1999

Wednesday, January 6

Illini Rooms

9:30	Welcome, Opening Remarks and Informational Items, Mike Gray

Keynote Session: Agricultural Biotechnology, A Revolution!

Mike Gray Presiding

9:40	Biotechnology and the Land Grant Institution: Future Roles and Responsibilities
	Steven Pueppke, Associate Dean, Research & Agricultural Experiment Station, University of Illinois at Urbana-Champaign
10:05	Bioethics in a New World
	Erich Loewy, Chair, Bioethics Program, University of California
10:30	Is Agricultural Biotechnology Sustainable?
	Michael Duffy, Director of the Leopold Center, Iowa State University
10:55	Break

Issue: Minimizing Pesticide Drift

Bob Wolf Presiding

11:10	Introduction and Background, Bob Wolf
11:20	National Coalition on Drift Minimization Video
11:50	Panel Discussion with Media
	Illinois Fertilizer & Chemical Association—Lloyd Burling
	Illinois Aerial Aviators' Association—Jim Perrin
	Illinois Farm Bureau—Kent Krukewitt
	U.S. Environmental Protection Agency—John Ward
	Illinois Department of Agriculture—Gerald Kirbach
	Farmland Insurance—Mike Kelly
	University—Allan Felsot
12:30	Lunch

Corn Rootworm: Status Report on Research Efforts

Murdick McLeod Presiding

1:30	Western Corn Rootworm Injury in First-Year Corn: What's New? Joe Spencer
1:45	Update on Corn Rootworm On-Farm Research Efforts in East Central Illinois, Matt O'Neal
2:00	Areawide Management of Corn Rootworms: Was 1998 a Success? Corey Gerber
2:15	Novel Formulations for Corn Rootworm Insecticides, Mickey McGuire
2:30	Spraying Soybeans for Rootworm Management: Our Stance, Kevin Steffey
2:45	Transgenic Insecticidal Cultivars for Corn Rootworms: Resistance Management Considerations, Mike Gray
3:00	Break

Weed Science: Emerging Issues

Fred Butt Presiding

3:15	Soybean Varietal Response to Sulfentrazone, Andy Hulting
3:30	Weed Competition in Corn, James Kells
3:45	Persistence of Soil Applied Herbicides, Bill Simmons
4:00	Perennial Weed Management in RoundUp Ready Soybeans, Jerry Doll
4:15	Woolly Cupgrass and Waterhemp: An Iowa Perspective, Micheal Owen
4:30	Genetic Variability in Weed Populations, Patrick Tranel
4:45	Control of Aquatic Weeds in Lakes & Ponds, Carole Lembi
5:00	Internet Sources for Pest Management, Dave Pike
5:15	Weeds 2000: What's on the Horizon? Aaron Hager
5:30	Adjourn

Mixer

5:45 to 7:00 PM	Illini Union Ballroom
	This mixer is sponsored by the Illinois Fertilizer and Chemical Association, and it is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

Thursday, January 7

Illini Rooms

Plant Pathology: Emerging Issues

Suzanne Bissonnette Presiding

8:30	Diplodia Ear Rot of Corn, Don White
8:45	Illinois Soybean Cyst Nematode Coalition, Rebecca Richardson
9:00	Soybean Cyst Nematode: Spread & Dissemination, Dale Edwards
9:15	Soybean Sudden Death Syndrome: Questions and Answers, Glen Hartman
9:30	White Mold: Expectations for 1999, Wayne Pedersen

Precision Agriculture & On-Farm Research

David Feltes Presiding

9:45	Precision Agriculture: Does it Pay? Don Bullock
10:00	Split-Planter Comparisons: An Industry Perspective, Louis Chapko
10:15	A Discussion of Variable Rate Nitrogen Applications, Emerson Nafziger
10:30	Break

Fertility & Water Quality Issues

Kevin Black Presiding

10:45	Nitrogen Balance in Illinois: Recommendations for 1999, Bob Hoeft
11:00	Managing Phosphorous: Agronomic and Environmental Concerns, Reggie Voss
11:15	Value of Buffer Strips for Wildlife, Dick Warner
11:30	Soil Health and Tillage, Michelle Wander
11:45	Lake Springfield Demonstration Project, George Czapar
12:00	AFRAP and Land Application Rule: Where are We Today? Warren Goetsch
12:15	Lunch

Food Quality & Protection Act

David Feist Presiding

1:15	American Crop Protection Association Perspective, Ab Basu
1:35	U.S. Environmental Protection Agency Perspective, John Ward
1:55	Illinois Farm Bureau Perspective, Nancy Erickson
2:15	University Perspective, Allan Felsot
2:35	Break

New Developments from Industry

Bob Dunker Presiding

2:50	FMC, Len Dobbins
3:00	DuPont, Mike Hughes
3:10	Novartis, Henry McLean
3:20	BASF, Gary Schmitz
3:30	Monsanto, Dave Shenaut
3:40	Pioneer, Louis Chapko
3:50	DeKalb, Joe Walsh
4:00	Rhone-Poulenc, David Feist
4:10	Valent, Julie Young
4:20	AgrEvo, Daren Bohannan
4:30	American Cyanamid, Fred Arnold
4:40	Dow AgroSciences, Joe Pafford
4:50	Bayer, Brian Wade
5:00	Zeneca, Susan Curvey
5:10	Garst, Von Kaster
5:20	Adjourn

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Biotechnology and the Land Grant Institution: Future Roles and Responsibilities

Steven G. Pueppke

Biotechnology describes a bag of new tricks that scientists have put together over the past 25 yr for the purpose of modifying living organisms. The prefix *bio* means life and *technology* refers to the application of tools and techniques. Geneticists and plant breeders have labored for decades to improve crops by methods that include introgression of traits from related species. The new tricks of biotechnology take this strategy one step farther, allowing scientists for the first time to transfer genes between distantly related organisms, including jumping the boundary between kingdoms—both animal and microbial genes can be inserted into and expressed within plant species.

After more than a decade of talk about potentials but few actual payoffs, the late 1990s are beginning to see widespread impacts of biotechnology at the level of farmers and consumers. Today, 27% of all U.S. soybean [*Glycine max* (L.) Merrill] acreage is planted with varieties modified for herbicide resistance. Similar genetically modified varieties of corn (*Zea mays* L.), cotton (*Gossypium* spp.), and other crops have made inroads, and all projections are for increases—in acreages planted, in numbers of available varieties, and in crops that are being modified by biotechnology.

The Promise of Biotechnology

Genetic modifications of crop plants have been assigned to 4 major categories, which are sweeping across the face of American agriculture. The first of these categories involves input traits, which are of primary benefit to the farmer. Herbicide, disease, and insect resistance are in this category. *Rhizobium* bacteria that are genetically engineered for enhanced symbiotic nitrogen fixation also fit into this category. In each case, the grower's inputs are reduced because less herbicide, fungicide, insecticide, or nitrogen fertilizer must be applied. Many consumers are aware of biotechnology as it applies to input traits, but in most cases, they are not obviously affected.

The second category includes genetic modifications that have a direct affect on consumers because they are targeted for output traits. Tomatoes (*Lycopersicon* spp.) engineered to stay firm and not become mushy fall into this category, as do fruits with modified levels of solids that influence the quality of sauces and other products. Other examples include crops with elevated or decreased levels of proteins that are important for human or animal nutrition.

The third category includes modification of traits that influence the ways that plants adapt to growth conditions. The productivity of some soils is limited by flooding or salinity. Other growing areas are subject to drought or to occasional frosts late in the spring or early in the fall. We know that some plants flourish under these suboptimal conditions, and so the strategy is to identify the genes that permit such adaptations and then to transfer them to important crop species. Although these physiological processes are complex and will be difficult to manipulate, the benefits could range from reclamation of lost agricultural lands to the availability of new fruit varieties able to set well in spite of spring frosts.

The fourth category of genetic modifications aims at nothing less than the conversion of plants into living factories that produce raw materials and biomass. This outcome is particularly attractive because it substitutes renewable, domestically grown raw materials for petroleum, a nonrenewable resource that must be

imported. A variety of experimental and specialty products also falls into this category. A firm in Texas has already commercialized a new corn variety that produces a diagnostic reagent for vitamin B_{12}. This protein can be extracted from eggs, but it takes a ton of them to produce the amount of reagent that can be obtained from just 4 bu of genetically modified corn. Plants that produce antibodies also are being tested experimentally. These and other products of biotechnology will have major future impacts on American agriculture.

Role of Land-Grant Universities

Private firms are investing literally of billions of dollars as they carve out specialized niches in agricultural biotechnology. Land-grant universities, including the University of Illinois, have much more limited funding and are responsible for a variety of programs, not all of which focus on biotechnology. But universities do have important roles in the biotechnology revolution.

One role is to supply raw materials in the form of intellectual talent. Every year, tens of thousands of students are trained at land-grant universities, not just in biotechnology, but in agriculture in the broadest context. Many of these graduates accept positions in the biotechnology sector and go on to make major contributions.

Land-grant universities also are major players in basic biotechnological research. Genes that confer resistance to pests have been discovered on these campuses; extensive genome sequencing and mapping efforts are underway, and desirable traits are being moved into new species with the tools of biotechnology. Land-grant universities also have a long and ongoing tradition of relating the function of plant genes to biochemical and physiological processes that have specific effects on plant growth. A clear understanding of these relationships is crucial if we are to turn basic knowledge into improved crop varieties with new traits.

Finally, land-grant universities have the expertise and capacity to analyze the social and economic impacts of the biotechnology revolution, on both a local and global scale. These impacts are proving to be considerable. Resistance to genetically modified plants can be great, especially in Europe, where a recent poll confirmed that 82% of Germans would not eat a Butterfinger candy bar if they knew that it contained products of genetically engineered corn.

The introduction of genetically modified crops, many of which may be grown under contract, will potentially influence the independence of individual farmers, their marketing strategies, and ultimately, the structure of rural communities. We are beginning to see these impacts and the pace will accelerate in years to come. The challenge to the land-grant universities is to help guide the process and maximize the benefits of the advancing biotechnology revolution for our agricultural constituents.

BIOETHICS IN A NEW WORLD

Erich H. Loewy

Ethics is the discipline that seeks to search for answers to what is "good" and what is "evil." In so doing, it relies on philosophical tools of analysis and cannot, in a multicultural world, rely on religion, culture, tradition, or other belief systems. In the way I shall view ethics, it is not a discovery of immutable truths but rather an ongoing search for ways of acting. The rules and precepts of ethics, thus, are something we in the human condition craft and that have to be attentive to context and situation. The method we use in thinking about the problems of ethics is not different from the method we use in thinking about problems of science: it is, basically, establishing and testing hypotheses.[1] In crafting an ethic that can be viable across different religions, belief systems, cultures, and traditions and still escape the trap of ethical relativism, we must rely on a human framework of capacities and experiences shared by us all.[2] The reason we trouble ourselves to think about ethics in the first place is due, as Rousseau long ago pointed out, to 2 other fundamental human capacities: an innate sense of compassion that makes us uncomfortable in the face of the suffering of other creatures and the sense of self-regard eventuating in the sense of self-preservation, which in making choices must often balance our sense of compassion.[3] Within such a framework and by using the common logic that all humans likewise share, we do not permanently solve either problems of science or problems of ethics but seek to make indeterminate situations more determinate.[3] An ethic thus crafted can supply some basic precepts to which we can all subscribe but must leave sufficient elbow-room for different expressions of these precepts.

The ethical problems of today challenge us. New scientific knowledge and the immediacy with which such knowledge is translated into action have raised serious, new and ever-increasing ethical problems. Traditionally, knowledge itself has been considered to be "value free" and to become ethically problematic only when such knowledge is translated into technology and consequently into action. Contrary to this traditional point of view, Hans Jonas has argued that the profound changes as well as the speed with which such changes occur in today's world, entail looking less neutrally at knowledge itself.[4] In his view, the consequences of our newly developed technologies have become both far less and far more readily predictable: far more because we have far more sophisticated methods of prediction and far less because changes are so rapid and the nature of these changes is often so profound that even our most sophisticated methods of prediction do not serve us well. This interpretation, of course, is true not only in the "hard" sciences, but and with equal force in the social sciences. Professor Jonas has argued that our ethical focus must change: new knowledge and new technologies must be used only if their side effects are predictable and do not entail risks.

Such an argument, enticing as it may be, stands in opposition to "logical positivism" that saw and sees new knowledge and new technology as ever-furthering the interests of humankind. There are problems with both points of view: logical positivism has, at the very least, been found wanting, but the opposite view would condemn the future to repeat the present and would preclude all advances that sciences offers. It would, in a sense, be hubris for it would clearly say that humans have reached the apex of positive development and need search no further.

Science and technology cannot, and serve humankind, be allowed to be uncontrolled. Although knowledge in and of itself may be value neutral, the potential for the

application of such knowledge and the dire consequences such application may have for the future must be seriously weighed. We must, in other words, rigorously control what we undertake and how we undertake to do it. Necessarily, if it is to have teeth, hampering progress and discontinuing the quest for new knowledge is a form of censorship—something offensive and dangerous in itself. And yet there is some knowledge and the technology derivable from it that clearly pose great danger to all of us. The question changes—not what should the limitations be but, if some modicum of control needs to be exerted, who is to make the decision and who is to exercise the power?

The only hope for controlling and channeling science, technology, or social experiments is through and by the maintenance or creation of a democratic, interactive society. Democracy is more than merely political democracy: political democracy not underwritten by the necessary conditions for its function is a sham. For political democracy to function at least 3 preconditions are needed: personal democracy (i.e., a state of affairs in which we dialogue with and respect the opinions of others), economic democracy (i.e., the supply of minimal necessities of life to all), and educational democracy (i.e., an equal chance for all to develop their talents and interests).[5] Given such a state of affairs a social consensus among individuals enmeshed in their community can be developed. Only when such a social consensus finds expression in guidelines for scientific advance and technological development can we hope to use science for the ultimate benefit instead of for the impoverishment and destruction of humankind.

Footnotes

[1] John Dewey argues (and I think rightly) that the basic method of investigation or inquiry is the same in science and ethics. See: John Dewey: The Logical Conditions for the Scientific Treatment of Morality. In: ed. J.A. Boydston and D. Rucker The Middle Works of John Dewey Vol. III. Carbondale, IL: Southern Illinois University Press; 1988.

[2] The idea that a common framework for the crafting of a multicultural ethic exists is developed extensively in Loewy, E.H.: Moral Strangers. Moral Acquaintance and Moral Friends: connectedness and its conditions Albany, NY: State University of New York Press; 1997.

[3] Rousseau emphasizes what he calls the primitive sense of pity ("l'impulsion intbrieure de la compassion") as well as the sense of self-preservation ("la conservation de soi-même"). It is this sense of compassion that Schopenhauer considers to be the driving spring ("Triebfeder") of ethics. See: Rousseau, J.J.: Du Contrat Social (R. Grimsley, ed) Oxford England: Oxford University Press, 1972 and Rousseau, J.J.: Discours sur l'oriqine et les Fondements de l'interieure parmi les Hommes Paris, France: Gallimare; 1965. An excellent translation of these works is Cole GD: J.J. Rousseau: The Social Contract and the Discourses New York, NY: Everyman's Library; 1993. Schopenhauers commentary—which is critical—can be found in Schopenhauer A: Preisschrift uber die Grundlagen der Moral. In: Arthur Schopenhauer Kleinere Schriften (Band III Arthur Schopenhauer's Samtliche Werke) Frankfurt a/M, Deutschland: Suhrkamp Taschenbuch 1989.

[4] Jonas, H: The Imperative of Responsibility Chicago, IL: University of Chicago Press; 1985.

[5] Dewey, J: Creative democracy: the task before us. In: Boydston JA, Sharp A., eds.: John Dewey the Later Works 1939–1941 Carbondale, IL: Southern Illinois University Press 1991 p. 224–230. See also: The Public and its Problems IN: John Dewey, the later Works 1925–1953 (eds. J.A. Boydston and B.A. Walsh) Carbondale, IL: Southern Illinois University Press; 1991.

IS AGRICULTURAL BIOTECHNOLOGY SUSTAINABLE?

Michael Duffy

Good morning! I appreciate the opportunity to be here with you today and to be a part of this conference. I am going to start with some comments and then I hope we will have time for discussion.

When I was first called and ask to give a talk addressing the sustainability of biotechnology I naively thought that it won't be too hard; there has been so much written about the topic that all I will have to do is read and summarize a few articles. Unfortunately, that wasn't the case. Yes, there has been a lot written about biotechnology and sustainable agriculture. But, the more I read, the less clear the answers became and in fact, I changed some of my own opinions regarding biotechnology and the role it can play.

So instead of being a relatively easy assignment, this has turned out to be a very difficult but fascinating one. I hope that you will find something you can take from this and use in your everyday life.

As I started to pull my thoughts together after the background preparation, I really struggled with knowing how to say something that hasn't already been said. I also struggled to determine what were the most important messages I had learned regarding the sustainability of agricultural biotechnology. My first inclination was simply to say, "it depends" and sit down. Perhaps when I am done you will think I should have followed my first inclination, but that wouldn't justify my coming here today, so I am going to proceed.

I want to preface my remarks by telling you a little about who I am and the worldview that I hold. I think that this is extremely important because how one looks at the sustainability of biotechnology is greatly influenced by their worldview. I also want to devote a few minutes to defining exactly what we mean by biotechnology and sustainability. This will be followed by a discussion of several of the more important issues related to the sustainability of biotechnology. Finally, I will conclude with a few of my own thoughts regarding the direction and future for agricultural biotechnology.

My answer to the question of whether agricultural biotechnology is sustainable, really is "it depends." It depends on which direction the biotechnology research takes. It depends on how serious some of the unintended consequences might be. And, it depends on how you define the terms.

I am an agricultural economist employed as a professor of economics and an Extension economist at Iowa State. In addition to the usual professorial and extension duties, I am the associate director for the Iowa State's Leopold Center for Sustainable Agriculture and the Professor-in-charge of the Iowa State Beginning Farmer Center.

All of this influences the way that I view the world. As an economist I believe in the market as an efficient mechanism for allocating resources. However, just as I believe in the efficiency of the market, I also know there are market failures. These failures take several forms. Difficulties valuing externalities is one example. Public goods, such as air and water, are another area where the market cannot efficiently cope with all the issues. Allocating resources between generations is another problematic area for the market. Finally, I think that concentration of market power is something that will lead to the failure of markets as an efficient mechanism for allocating resources.

My work with sustainable agriculture and beginning farmers also influences the way I view things. I firmly

believe that humans are a part of the natural system and not apart from it. The best way for us to achieve a sustainable agriculture is not to try continually to conquer the problems of the natural world but to try to understand them and to work as a coinhabitor rather than a conqueror. For every action there is a reaction. We need to understand and try to work towards minimizing the unexpected and negative consequences of our actions.

Change is inevitable but we have some control over the direction of the change. Technology must be controlled by humans, not control humans. We have to change to grow and survive as Kathleen Norris wrote, "Disconnecting from change does not capture the past. It losses the future."

Defining the Terms

It is very difficult to define accurately either sustainability or biotechnology. They are terms that have long been misused and abused. They are also terms that conjure up an immediate reaction in some people, either positive or negative. The biggest difficulty with the terms is that they are generic and broad-based.

Biotechnology has been labeled "a misleading expression because it conveys a singularity or unity to what is actually a tremendously diverse set of activities and range of choices." (Buttel 1985) A USDA publication notes, ". . . biotech processes and products are so diverse and have so little in common with one another that it is difficult to construct valid generalizations about them. Broader than genetic engineering and gene splicing, biotech includes tissue, cell, and embryo culture; protoplast fusion; bioregulation or hormonal control of physiological and metabolic processes; production of gene-controlled products; directed plant breeding; and fermentation processing." (USDA 1987)

Michael Fox provides a chronological presentation of the events leading up to the present day. Fox begins with the breeding experiments by Mendel in 1869. (Fox 1992) Others feel that the roots of biotechnology, especially as it relates to traditional plant breeding, can be traced back to the earliest days of agriculture and the domestication of plants and animals. Keeney, however, points out, "In contrast, the new agricultural biotechnologies provide the tools for molecular and cellular approaches to altering plants and animals." (Keeney 1998)

This is a big distinction between more traditional plant and animal breeding and biotechnology. The traditional methods were limited to using only materials that were biologically similar. Now with the biotechnology capabilities, scientists are able to construct animals and plants that would never be possible using conventional breeding techniques.

Sustainability is equally hard to define. In general, it has been used in connection with sustainable agriculture. However, the term has also been used in connection with development efforts. Anderson talks about "at least three distinct meanings for the concept of sustainable agriculture that have already appeared in the literature—sustainability as food self-sufficiency, sustainability as environmental quality, and sustainability as community." (Anderson 1988) The terms sustainable agriculture, ecological agriculture, low-input, and so forth have been used for a long time. Lockeretz compares and contrasts several of these different terms. (Lockeretz 1988)

The 1987 Iowa Groundwater Protection Act, which was the legislation that created the Leopold Center, defined sustainable agriculture as, "the appropriate use of crop and livestock systems and agricultural inputs supporting those activities which maintain economic and social viability while preserving the high productivity and quality of Iowa's land."

A definition of sustainable agriculture will usually include at least three things: individual farm profitability, environmental quality, and impacts on the rural community. Different definitions may feature modifications of these points and add the need for an adequate or self-sufficient food supply. This latter point is one worthy of a few comments.

Many proponents of biotechnology say that this technology is necessary to feed the world. They argue that if we do not use biotechnology we will have starvation and the other ills associated with malnutrition. This is certainly a concern; however, the evidence shows that it is not the hungry that are being fed but rather the affluent, i.e., those who can afford to buy the food. The Green Revolution also was promoted as a means of eliminating world hunger. Food production has increased but we still have hungry people. The problem is not one of production but rather a problem of distribution and politics. Ho Zhiqian, a Chinese nutrition expert, was quoted as saying, "Can the Earth feed all its people? That, I'm afraid, is strictly a political question." (Reid 1998) As we think about the sustainability of biotechnology, we must not confuse wanting the world to be fed with wanting to feed the world.

Before discussing some of the major issues facing biotechnology and sustainability it should be noted that the majority of people agree with Anderson "that biotechnology is intrinsically neither supportive of nor contrary to the goals of the alternative agriculture movement." (Anderson 1988) The Director of the Leopold Center for Sustainable Agriculture concluded "there is nothing inherently wrong with biotechnology." (Keeney 1998) Even Fox, who does not particularly view the recent developments with favor, says, "We need not abandon biotechnology . . ., but we must use it prudently, with respect, humility, and compassion." (Fox 1992)

Issues: Public vs. Private Research

The biggest question about the sustainability of agricultural biotechnology is in which direction it will go. The answer to that question is the single biggest factor in determining the sustainability of biotechnology. The answer also is not entirely clear and is still evolving.

There are two general directions in which biotechnology can proceed; it can be solely focused on private gain or it can have the public good as its primary goal. The two directions are not necessarily mutually exclusive but the predominance of one over the other will significantly influence the type of biotechnologies that are developed. And, this in turn will influence the sustainability of biotechnology.

At the heart of this matter is the distinction between public and private research. Private research is done for private gain whereas public research should be done for the public good. Huffman and Just have studied this issue in considerable detail. They note that "since 1980, the growth in agricultural research funds (in constant prices) has been largely in the private sector . . ." (Huffman and Just 1997)

There are two ways that private firms can conduct research in biotechnology. They can conduct the research themselves or they can contract with other private or public institutions to conduct the research. Between 1960 and 1995 the share of revenue going from the private sector to the state agricultural experiment stations for research has doubled, from 7 to 14 percent. There are potential conflicts of interests with these arrangements because "open sharing of R&D results is seldom in the private sector's best interest, and it is generally in the best interest of private firms to seek exclusive rights to innovations from projects that they fund in public research institutions." (Huffman and Just 1997)

Anderson identified three types of biotechnology research. One is research into the basic molecular biology of plants and animals, which he concludes is neutral with respect to sustainable agriculture. The second type is "research resulting in a greater reliance on chemical pest control, monoculture, chemical fertilization, animal drug use, etc." This research, Anderson feels, should not be done by the public sector. His primary reason for this position is similar to the findings of Huffman and Just and he notes, "the primary beneficiaries of such research are private firms, those who produce the agrichemicals . . ." Finally, the third type of biotechnology research is that which contributes to the goals of sustainable agriculture. Anderson feels that this should be an area of emphasis for public research expenditures.

Huffman and Just are critical of the arrangements being made with respect to the private and public research institutions. They note, "a public research institution should focus on producing advances in general and pretechnology science that ultimately may be complementary to private R&D activities and conduct applied research in areas where the innovations are socially beneficial but no private market exists. . . ." (Huffman and Just 1997)

Many others discuss the direction of biotechnology research and point to the implications of that direction. Private firms are the primary funders of current research that will not likely lead to the development of sustainable biotechnology for agriculture. Many argue that if only the private sector is doing the funding, the direction will be to either prolong the current chemically intensive systems or develop replacement systems that still rely heavily on the companies providing the seed and materials needed for production.

One of the major difficulties of the private sector doing or influencing most of the research in biotechnology is the resulting concentration of power. Many authors warned that this could become a problem, and today we have seen many mergers and joint operating agreements in the seed industry. This biotechnology revolution in the seed industry has "promised huge profits to the big chemical companies that increasingly are influencing their development and marketing." (Anthan 1997)

The 1998 recipient of the World Food Prize, Badrinarayan Barwale, commented in his acceptance speech that "without the development of a seed industry, agricultural production is difficult to increase. This provides a great challenge and opportunity to the global seed industry to be of help to these underdeveloped countries." (Perkins 1998) But the seed companies are

in business to make money. If the impoverished do not have the financial resources to pay for the seed then it will only be through the humanitarian actions of the seed companies that they receive the seeds. The Green Revolution taught us that simply increasing production will not be enough to alleviate starvation, and increasing the costs of production can have many unintended consequences for the less affluent.

The future direction of the biotech research has far-reaching implications beyond who is actually doing the research. The structure of agriculture also will be affected. New biotechnologies that increase the reliance on capital intensive techniques will further speed the decline in the number of farmers, especially younger farmers who do not have the capital resources to participate. Research to overcome salinity problems arising from irrigation will continue farming where perhaps it should not have been occurring in the first place. Research to expand production in the tropics under the auspices of "feeding the world" would have a tremendous impact on the biodiversity of the planet.

On the other hand, research into new crops and new uses could potentially increase biodiversity. But, who will do the research and which direction will it go? The answer to that is "it depends."

A new wrinkle in agriculture brings about many other changes. When talking about biotechnology and the other 'revolutions' that have occurred in agriculture, Anderson notes, "They are steps along the road of cultural and genetic evolution-large scale systemic transitions that reshape societies, governments, economies, ecosystems. Most of them have uneven consequences-good for some, bad for others-and some have costly and destructive side-effects. Consequently, when another agricultural revolution is seen to be coming down the road, as one certainly is now, different people and groups will react with vastly different degrees of enthusiasm-and offer vastly different predictions about what the consequences will be." (Anderson 1996)

This is important to remember when evaluating the sustainability of biotechnology. There will always be winners and losers, but do the winners gain enough to offset what is lost? In the case of biotechnology, some of the applications will likely displace a cash crop for some of the Third World countries. Arguably, the land devoted to the displaced crop could go towards other food production but the point is that there are unintended consequences from the introduction of any new technology.

Issues: Unintended Consequences

A second major issue surrounding the sustainability of biotechnology concerns the potential for unintended side effects. This is also a major point of contention between the proponents and the opponents of biotechnology.

One of the key points of uncertainty is the impact of the modified organisms in the environment. There are those who feel that the introduction of the modified organisms has the potential for causing considerable disruption. This would be similar to the introduction of exotic plants and animals that ended up as pests or drove out beneficial native species. Others respond by saying, "those introductions involved organisms totally unrelated to the ecosystem . . . new biotech products involve modification of organisms that are indigenous to the parent ecosystem." (USDA 1987)

A person's worldview will greatly influence how seriously they consider this problem for biotechnology. Some feel "that the majority of scientists who serve biotechnocracy operate on the arrogant and paternalistic assumption that science knows best. Nature isn't perfect, their reasoning goes, but it can be improved upon. Likewise, science isn't perfect, but any problems that might arise from the life sciences' meddlings with nature can easily be fixed." (Fox 1992) On the other side are those who feel that any problems that arise will be minimal and "while there is scientific uncertainty over some biotechnology products, the vast majority will not differ much from existing agricultural products." (USDA 1987)

The fact that biotechnology can produce some unintended consequences should not come as a surprise to anyone who seriously considers the issues. Monarch butterflies have been adversely affected from ingesting the pollen from *Bt* corn on milkweed. Glyphosate resistance has been reported in some plants, and while not directly related to biotechnology, the widespread use of the herbicide can increase the speed which resistance develops. There are many other such examples.

The specter of unintended consequences is referred to almost every article or book on agricultural biotechnology. How this aspect is regulated and dealt with will help determine consumer acceptance of biotechnology products. Peter Bloome from Oregon State University has written that "the greatest threat to biotechnology is the unwillingness of its proponents to publicly admit that there will be significant, unanticipated, negative

impacts from these new technologies and their applications. The impacts, negative and positive, will be biological, economic, and social in nature." He goes on to say, "the reality of the negative impacts does not argue against pressing ahead with biotechnology. But it does argue for humility, alertness, and resources held in reserve to address negative impacts."

I believe there will be unintended impacts from biotechnology that will determine the sustainability of this new technology. Some of the consequences will be similar to those that occur whenever there is a new technology introduced. However, other impacts will be specific to this type of technology. I concur with many other writers that the ability to manipulate genes brings with it a tremendous responsibility to act in ways that are constructive not destructive. We need to think of the power of the new technology with humility, not with the attitude that it 'moves us closer to being God.'

Many of the impacts discussed previously in connection with the type of research would also fall under the auspices of unintended consequences. Winners and loser, changes in the structure of agriculture, and concentration of market power are all examples of unintended consequences.

There will be sociological impacts from biotechnology that will have an influence on the sustainability of this technology. Disruption of lives, moving people off the land and into cities, and so forth, are all possible outcomes that must be considered and dealt with if biotechnology is to represent a truly innovative and monumental move toward betterment of all people.

Issues: Ethical and Other Considerations

There are some that question biotechnology on ethical grounds, especially as it relates to animals. The major questions being raised concern the ethics of using animals essentially as factories to produce antibiotics or other drugs. This is a point discussed by Fox.

In addition, there are concerns expressed regarding the health of the animals being used. Changes in one function of the animal, for example increasing milk production, can have other results throughout the animal's body and vital organs. Does the animal suffer needlessly?

These are difficult and thorny problems that many scientists do not feel comfortable discussing. However, they are of direct relevance to any discussion about the future of biotechnology. Biotechnology gives humans the capability to directly intervene in the evolutionary progression. How will we use this power?

Biodiversity is another related issue where these is no clear-cut consensus on whether biotechnology will help or hinder sustainability. Some argue that by altering the gene patterns and changing characteristics of plants and animals, biotechnology is increasing biodiversity. Others feel that if biotechnology opens new areas to crop production, the resulting destruction of wildlife habitat and clearing of wilderness will result in a decrease in biodiversity.

Finally, the use of fossil fuels is an area that could be influenced by breakthroughs in biotechnology. If the path chosen is similar to the one that we are on today, biotechnology will lead to an increase in the use of fossil fuels in agriculture. However, certain applications of biotechnology could lead to a reduction in agricultural fertilizer use, especially nitrogen.

Conclusions

Whether or not biotechnology is sustainable is a question that is not easily answered. Most who study this issue feel that biotechnology is simply an extension of the plant and animal breeding work that has been underway for centuries and there is nothing inherently unsustainable.

However, if one feels that the current agricultural system is not sustainable, there will be questions raised as to whether or not biotechnology represents a truly new direction or simply a different path headed in the same direction. This is a question that, unfortunately, cannot be answered by looking ahead. Only with hindsight will we be able to determine if biotechnology offers a new beginning or a repeat performance.

One of the major biotechnology issues is that of public and private research. This one will have profound effects on the face of agriculture beyond the discussion on biotechnology. We are at a point where, with the demise of the major centrally-planned economies, there is a general feeling of the superiority of the private enterprise system. This superiority is viewed almost as an "either-or" type argument and this is most unfortunate. The discussion should not be whether there is a role for public research, rather the discussion should be about the appropriate role for public research. The United States was fortunate in the past to have leaders who knew that only through basic agricultural research would this country be able to flourish. Today we have

seen an erosion of support for public agricultural research and we are on our way down a path that may not serve us well in the future.

Biotechnology is truly remarkable. Rather than being a final break with humans from the natural cycles, I feel that it represents a further complication of the issues. When you cannot control much, you don't have a lot of concerns, but the more control you gain, the more variables there are and the more difficult the decisions become. I don't view biotechnology as the technology that will finally put humans "on top." Rather, I view it with awe and a sense of the tremendous responsibility that it entails. Some say it moves us closer to God. I wish that was truly the case and that biotechnology will not continue to foster the arrogant mentality that has developed much of our technologies and approaches to date. We must proceed but carefully. The greater the potential impacts of any change, both positive and negative, the more caution we should exercise. Biotechnology is no different in that regard.

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NATIONAL COALITION ON DRIFT MINIMIZATION

Bob Wolf

The misapplication of crop protectant products is a major concern in the application industry. One form of misapplication is spray drift. Unfortunately, when applying crop protectants there is always a chance some chemical will escape from the target area. Drift is of concern because it removes the chemical from the intended target making it less effective and deposits it where it is not needed and often not wanted. The second concern is generally the most critical because the pesticide becomes an environmental pollutant in the off-target area. Off-target deposits can injure susceptible vegetation, damage wildlife, injure people, and contaminate air and water supplies. Problems can result when carelessly applied pesticides, especially herbicides, drift and cause damage to economically or aesthetically important crops. In all cases, there will be an added expense to the process of applying the crop-protectant materials.

Although drift cannot be completely eliminated, the use of proper equipment and application techniques will maintain drift deposits within acceptable limits. The initial recommendation for drift control is to read the pesticide label. Instructions are given to ensure the safe and effective use of pesticides with minimal risk to the environment. Chemical company surveys indicate that a large percentage of drift complaints involved application procedures known to be "off-label."

There are 2 ways that chemicals move downwind to cause damage: by particle and by vapor drift. Vapor drift is associated with the volatilization of pesticide molecules and their movement off-target, making it independent of the application. Particle drift is the off-target movement of spray particles formed during application. The amount of particle drift depends mainly on the number of small, driftable particles produced by the nozzle. Although excellent coverage can be achieved with extremely small droplets, decreased deposition and increased drift potential limit the minimum size that will provide effective pest control.

To gain better information about minimizing spray drift, the Spray Drift Task Force (SDTF) was organized in 1990. This task force, made up of 38 major agricultural chemical companies, pooled funds (≈$18 million) to conduct standardized research and collect data that the United States Environmental Protection Agency (US EPA) could use to formulate product label language regarding application methods to reduce spray drift. There were 21 studies generating 40 reports in the application areas of aerial, airblast, ground, and chemigaton. After completion of the research, another goal of the SDTF was to disseminate the information gathered from the research to the spray application industry. With better knowledge regarding the causes of spray drift, better decisions are possible about spraying crop protectants and hopefully minimizing spray drift.

The National Coalition on Drift Minimization (NCDM) was organized in 1995 to help meet the educational goal of the SDTF. The coalition membership is comprised of representatives of the US EPA, state lead agencies, USDA-CREES, applicators, product manufactures and distributors, private applicator interests, American Association of Pesticide Safety Educators (AAPSE), American Association of Pest Control Officials (AAPCO), National Agricultural Aviation Association (NAAA), Agricultural Retailers Association (ARA), and university agricultural engineers.

The NCDM meets every 3 mo, typically in Washington D.C. The coalition is organized into 3 subgroups; the educational, regulatory, and technology subcommittees.

To date, all the subcommittees have been active in strategizing for ways to help minimize spray drift. The regulatory subcommittee collected drift enforcement data from several states. The data collected provided valuable information of the status of spray drift nationally. The committee is planning a 2nd survey in late 1998. Eventually, the information gathered will help determine positive outcomes in the educational efforts of the NCDM. The technology subcommittee is currently collecting information regarding new spray technology to help focus future coalition educational efforts.

The education subcommittee has completed a survey to assess the status of drift education in each state. The survey also was used to determine what types of educational training materials were available for use in drift education programs. As a result of what was learned in the drift education profile, the coalition has decided to establish a national drift education curriculum to help guide the development of a series of educational programs that will facilitate the dissemination of spray drift minimization information.

The first educational program from the NCDM is a video entitled, "Straight Talk About Minimizing Spray Drift—A guide for applicators." The video, directed by Bob Wolf is approximately 29 min in length and is designed to inform those involved in the application of crop protection products about the importance of the spray drift problem. It also will cover the technical aspects of spray drift by using a spray drift demonstration table to highlight the influence of nozzle type, pressure, and wind on spray drift.

Additional programs created to help support the NCDM's national drift education curriculum are available. The slide set "Minimizing Spray Drift" with script (20 slides) is available for shorter pesticide applicator training programs. A 2nd slide set, "Spray Drift Management" with script (49 slides) is available for use in a more detailed drift-education program. Both of these programs are available for downloading from the World Wide Web. They can be accessed from the following address (Bob Wolf Homepage): <<http://www.age.uiuc.edu/faculty/rew/index.html>>.

Both of these slide sets are PowerPoint programs (Version 97) and can be used to develop a slide set or as an on-screen presentation. The files can be adapted to the audience. Special animations are also possible depending on the creative nature of the presenter. The guide and script are MS Word files (Version 97) and should be downloaded to support the slide sets.

The NCDM will continue to develop educational programs to support the goal of minimizing spray drift. By increasing the educational efforts by, to, and for, the application industry, it is hoped that the misapplication of crop protection products, specifically spray drift, will not be as critical an issue in the future as it is today. With less spray drift, the crop protection industry will be able to maintain the use of many valuable crop protection materials.

WESTERN CORN ROOTWORM INJURY IN FIRST-YEAR CORN: WHAT'S NEW

J.L. Spencer, S.A. Isard, and E. Levine

The western corn rootworm (*Diabrotica virgifera virgifera* LeConte) is the most serious pest of corn (*Zea mays* L.) grown in the Midwest (Levine and Oloumi-Sadeghi 1991). Since the late 1980s, the previously effective practice of annually rotating corn with soybeans [*Glycine max* (L.) Merrill] for western corn rootworm control has failed across an expanding area in Illinois and Indiana, and in parts of Ohio and Michigan (Onstad et al. 1998). Previously, adult western corn rootworm displayed a strong fidelity toward cornfields for feeding and oviposition by females. Once mated, many beetles dispersed from their natal field and settled in nearby cornfields where they continued feeding and laying eggs. For a female's offspring to survive, her eggs must be laid and hatch where corn will be grown the following year. Successful development of western corn rootworm larvae requires that they feed on the roots of corn (or a limited number of other grasses) (Gray and Luckmann 1994). Crop rotation exploits the allegiance of western corn rootworm to corn and the females' habit of laying their eggs in cornfields, by annually alternating the production of corn with another crop (usually soybeans) on which western corn rootworm larvae cannot develop. Under a corn–soybean rotation, western corn rootworm eggs that were deposited in corn the previous year (and that overwintered in the field) hatch in a soybean field. Emerging larvae are unable to develop on soybean roots and they die (Levine and Oloumi-Sadeghi 1991).

As a management tool for western corn rootworm, crop rotation has been a great success; however, because of its wide adoption and effectiveness, the practice itself has been a very strong selecting force for adaptations that would allow western corn rootworms to reproduce in spite of rotation (Gray et al. 1996, 1998). The northern corn rootworm (*Diabrotica barberi* Smith & Lawrence) adapted to crop rotation through selection for a prolonged egg diapause. Where rotation is prevalent, a high proportion of northern corn rootworm eggs lies dormant in rotated fields for 2 or more winters instead of the normal 1 winter. Thus, northern corn rootworm effectively waits until corn is once again available where the eggs were originally laid (Levine et al. 1992). A similar prolonged diapause was initially suspected when a recent problem with western corn rootworm in first-year corn was recognized. We now know that western corn rootworm populations in areas where rotation is failing (i.e., problem areas) circumvent crop rotation by leaving cornfields, and the females lay eggs in soybeans and other crops rotated with corn (Spencer et al. 1997, 1998). What northern corn rootworm accomplished by shifting its developmental schedule, western corn rootworm achieved through a change in oviposition behavior (Levine and Oloumi-Sadeghi 1996).

For several years, we have been engaged in efforts to further characterize the behavior, physiology, and distribution of the new western corn rootworm variant in Illinois. This paper details our latest progress in monitoring the spread of the problem and our search to uncover aspects of western corn rootworm biology and behavior that will improve and enlarge our management toolbox.

General Methods

A micrometeorological measurement station (Campbell Scientific, Inc.) was established in 1 of three 4-acre soybean fields (Pioneer 9333 Roundup Ready) northeast of Urbana on land owned by the University of Illinois Foundation (Isard et al. 1998). Data from this station

enabled us to study the influence of temperature, wind speed and direction, atmospheric pressure, precipitation, and solar insolation (sunshine intensity) on western corn rootworm populations and their movement. This field was the focus of our most intensive western corn rootworm monitoring activity. The solar-powered weather station, located at the center of the field, made continuous measurements during the study period, recording means or totals for all parameters at 10-min intervals.

Vial traps were used to establish patterns of western corn rootworm abundance in a variety of settings. Traps were made from 60-ml amber-colored plastic vials with snap caps as described by Levine and Gray (1994). The bottoms of the vials were replaced with wire screen to prevent condensation within the traps. Ten 5-mm-diameter holes were drilled in the sides of the vials to allow beetles to enter. Inserts for the vial traps were prepared by spraying both sides of 21.6 by 27.9 cm sheets of acetate transparency film with a 1:1 mixture (vol:vol) of carbaryl insecticide (Sevin XLR+; Rhone-Poulenc, Research Triangle Park, NC) and water. Powdered squash (*Cucurbita* spp.) was sprinkled on the film and allowed to dry. The film was then cut into 2.5 by 7.6 cm strips and inserted into the vial traps, one strip per trap. Approximately 0.5 g of squash was applied to each insert. The powdered squash came from a dried *Cucurbita andreana* x *C. maxima* cross grown in 1979. Only fruit with high levels of cucurbitacin was used. Cucurbitacins are a group of compounds found in bitter squash, cucumbers (*Cucumis* spp.), and melons that make corn rootworms feed compulsively. Beetles randomly enter the trap and feed on the powdered squash and in the process ingest a lethal dose of insecticide.

To monitor the distribution of western corn rootworm across crop interfaces, vial-trap transects were established between adjacent fields of corn and soybeans (or other crops, including alfalfa (*Medicago sativa*) [Pioneer 5312] and oats (*Avena* spp.) ['Ogle']). Vial traps were tied to 150-cm tall polyvinyl chloride (PVC) posts spaced 30 m apart across corn and soybean fields from the edge nearest the adjacent cornfield. Trap placement height in soybeans was determined by the level of the soybean canopy, and traps were adjusted upward as the plants grew. Vial traps in corn were kept at ear height. Five trap locations were used in each corn or soybean field, and traps were checked for beetles weekly from late June until early September. Because vial traps contain the cumulative collection of insects over a sampling interval, they reveal abundance patterns typical of the week prior to when they were serviced.

In soybeans, oats, and alfalfa, western corn rootworm was sampled by making 100 sweeps across the soybean canopy of 1 soybean row by using a 38-cm-diameter sweep net while walking at a steady pace. Sweep samples provide an instantaneous measure of insect abundance in sampled locations. To immediately halt feeding and ensure that beetles were returned to the laboratory in good condition for later dissection, adults collected with sweep nets were killed by transferring them into a cooler of dry ice. In the laboratory, the beetles in each frozen sample were sorted; economically important insects were identified to species and sexed. All sweep-sample western corn rootworms were transferred to small vials and stored at –23°C until dissection.

Live collection methods allow retrieval of fresh western corn rootworms from cornfields, or other locations where western corn rootworms are easily visible. Containers for making live collections consist of a glass canning jar, with a screw top modified to accept a large plastic funnel mounted in the metal lid. While walking down cornfield rows for a fixed period of time, the operator knocks as many western corn rootworm adults as are encountered into the mouth of the funnel, whereupon they tumble into the collection jar through the narrow outlet of the funnel. If the beetles are not destined for experimentation, dry ice is placed in the collecting jar. Intense cold and the carbon dioxide released from small pieces of dry ice in bottom of the jar instantly kill beetles. Like western corn rootworms sampled with a sweep net, these adults were sorted, sexed, and kept frozen for later dissection.

Monitoring the movement of western corn rootworms involved the use of directional paired malaise traps whose openings permitted entry from only one direction. Each trap was made of 3.8-cm outside diameter schedule 40 PVC pipe covered with ≈13 m^2 of Toule (bridal veil fabric) and had a 1-m^2 opening. The sides of the trap converged at the back to give the trap a triangular cross-section. The roof of the trap sloped upward to the apex where a 10-cm circular opening was cut in piece of Plexiglas at the top. Mounted in the hole was a plastic collar into which a pair of nested 2-liter plastic soda bottles were inserted. Beetles entering the trap passed into the lower bottle and through its neck into the upper bottle. The interior surfaces of the upper bottle were coated with liquid Teflon to prevent adults from escaping before they were killed by an insecticide cube affixed in the cap of upper bottle. Each morning, the trap tops were removed and the accumulated beetles were sorted by species and sex. On 8 July, 16 traps were placed around the perimeter of 2 soybean fields in 8 pairs. Two pairs of traps also were positioned a first-year cornfield adjacent to our field site. Two additional

pairs of malaise traps, one in alfalfa and the other in oats, were placed opposite those in corn. At each site, one trap's opening faced away from the field and the other faced to the interior. Trap height was adjusted throughout the season so that the bottom of the 1-m^2 opening was at the top of the plant canopy. Traps in corn were kept at the elevation of those in the adjacent soybean, oat, or alfalfa field.

The malaise traps were used to monitor western corn rootworm immigration and emigration within the first meter of air above the oat, alfalfa, and soybean canopies. Insects trapped in malaise traps were collected daily between 8 July and 21 August. On 10 July, in the soybean field with the weather station, a 9-m-tall scaffold was erected. Two additional malaise trap pairs were attached to this structure at 4- and 8-m heights above the soybean canopy. These traps permitted measurement of western corn rootworm movement at a relatively high elevation.

Data Analysis

All figures depict mean values ± standard error of the mean (SEM), unless otherwise indicated. Following an analysis of variance, multiple comparisons were performed using Fisher's protected least significant difference (LSD) procedure at $\alpha = 0.05$. Data were normalized before analysis when variation in western corn rootworm abundance was the result of seasonal or geographical variation (i.e., changing population sizes over the season, higher western corn rootworm populations in some areas than others due to more or less corn growing around a site).

Statewide Sampling

During late July and August 1998, we took 271 sweep samples from soybean fields in 44 counties across Illinois, including all counties at risk for western corn rootworm oviposition in soybeans (based on 1997 population densities of western corn rootworm in soybean fields and documented economic injury). In most counties, 2 different fields were sampled (100 sweeps per sample) at each of 3 separate locations in the county. Only soybean fields with nearby cornfields were selected for sampling. After collection, beetles were transferred into coolers of dry ice and immediately frozen for later dissection. Figure 1 depicts the average number of western corn rootworms collected per 100 sweeps with a 38-cm sweep net in 1998. If a county was sampled in both 1997 and 1998, the 1997 average is presented in parentheses below the 1998 average.

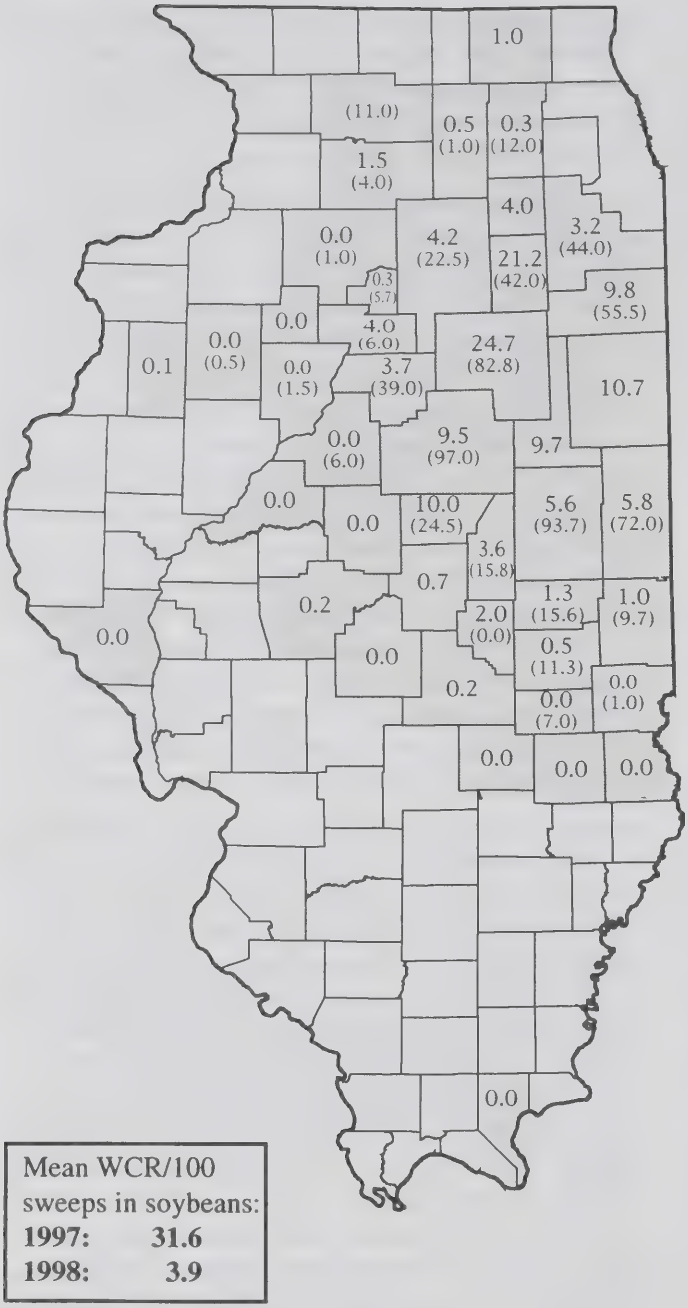
Abundance of western corn rootworm, northern corn rootworm, bean leaf beetle [*Ceratoma trifurcata* (Forster)], and Japanese beetle (*Popilla japonica* Newman) are summarized for state regions and presented in the smaller maps.

Compared with 1997 data, the average abundance of western corn rootworms in Illinois soybeans appears to have declined by almost 10-fold in 1998. Western corn rootworm abundance in soybeans declined in all but one of the counties (Moultrie County) sampled in 1997 and 1998 (1997: 0.0 western corn rootworm per 100 sweeps; 1998: 2.0 western corn rootworm per 100 sweeps). Western corn rootworm was significantly more abundant in the area previously identified as being at highest risk for western corn rootworm oviposition in soybeans than in areas north, south, or west of the problem area ($F = 33.8$, df = 270, $P < 0.0001$). Western corn rootworm was not detected in 14 of the sampled counties. These data suggest there was no significant expansion of the 1997 western corn rootworm problem area in 1998. Western corn rootworm continues to be present at low or undetectable levels in soybean fields west of the Illinois River and south of Interstate 70.

Western corn rootworm collected during state sampling in 1997 were dissected. Females from soybean fields in problem-area counties carried significantly more eggs than females from soybeans in nonproblem counties or than females in corn from any county (Figure 2). The proportion of females whose gut contents included both corn and soybeans was significantly greater for individuals in soybean fields (0.046) than for those in corn (0.007) regardless of the location's problem or nonproblem status ($F = 11.0$, df = 716, $P = 0.0009$). Females collected in soybeans and dissected were always mated ($n = 518$), whereas a small proportion (15 of 857, or 1.8%) of those from live collections in corn were unmated. The difference in proportion of females mated between corn and soybean fields was significant ($n = 1{,}375$; $\chi^2 = 9.17$; $P = 0.0009$; Fisher's exact test), all but 2 of the unmated females were collected in early July.

Remote Illinois Sampling Locations

In addition to sweep samples around the state, vial-trap transects running between adjacent corn and soybean fields were maintained at 4 University of Illinois Field Research and Demonstration Centers remote from the problem area: Northern Illinois Agronomy Research Center near Shabbona (DeKalb County), Northwestern Illinois Agricultural Research and Demonstration Center near Monmouth (Warren County), Orr Agricul-



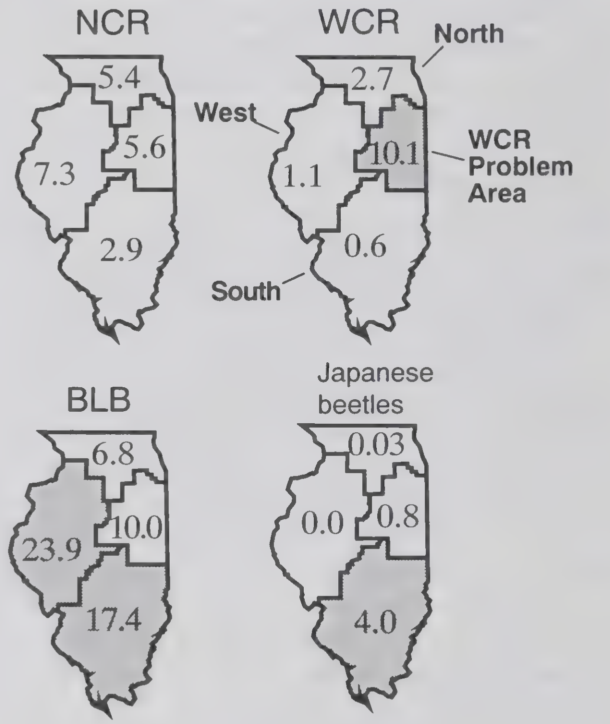


Figure 1 • 1998 abundance (beetles per 100 sweeps) of western corn rootworms (WCR), northern corn rootworms (NCR), bean leaf beetles (BLB), and Japanese beetles in Illinois soybean fields.

Sweep sampling conducted during July & August, 1998 (1997 data in parentheses).

(Shaded regions on small maps had significantly greater beetle abundance than unshaded ones)

tural Research and Demonstration Center near Perry (Pike County), and Dixon Springs Agricultural Center near Dixon Springs (Pope County). On-site cooperators deployed 5 traps each in a pair of adjacent corn and soybean fields. Sweep samples were taken weekly from the soybean field, and vial traps in corn and soybeans were emptied weekly at which time the insecticide-treated strips also were replaced. Identically configured vial-trap transects also were deployed at 2 sites in the Champaign County area (to be discussed subsequently).

The results from vial traps at the 4 sites and the local problem-area trap transects are presented in Figure 3.

Western corn rootworm was scarce in soybean field vial traps at the 4 remote sites. Western corn rootworm adults were found in corn at all sites. Of the sites, western corn rootworm was more abundant in soybeans than in corn only at the Champaign County problem-area sites. High western corn rootworm abundance in soybeans continues to distinguish problem from nonproblem areas.

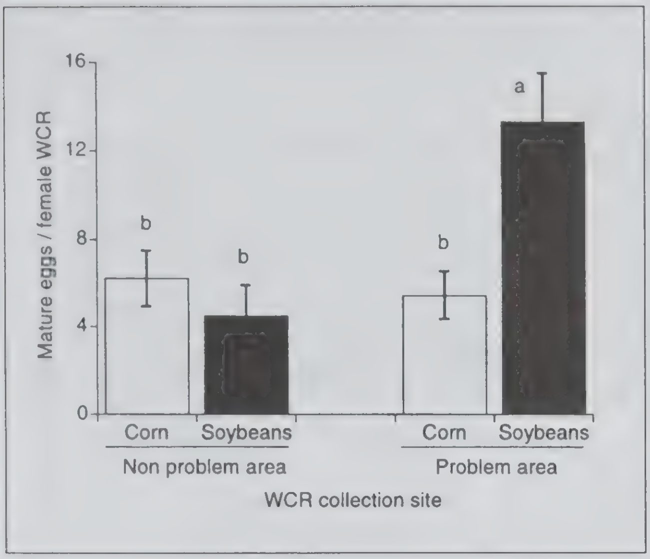


Figure 2 • Mean number of mature eggs carried by WCR females collected during statewide sampling in 1997. Collection sites in counties at highest risk for WCR egg-laying in soybeans and damage to first-year corn were considered to be in the problem area (Champaign, Ford, Grundy, Iroquois, Kankakee, Livingston, McLean,Vermilion, and Will counties). Bars bearing the same letter are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

Champaign County Sampling

During the 1998 growing season, vial traps, vial-trap transects, sweep samples, live collections, and malaise trapping methods were used to monitor the emergence, development, and dispersal of western corn rootworm populations.

Northeast of Urbana, a 41.5-km^2 network of vial traps was deployed in corn, soybeans, woods, and a commercial tree farm at road intersections between July and September (the same sampling locations also were used during the 1997 growing season). Twenty-five growers were involved in this effort. One vial trap per field was placed 10 m into each selected field. These traps were emptied weekly.

Even over this relatively small geographic region, western corn rootworm abundance was variable. Just as in 1997, however, western corn rootworm was collected at all locations where a trap was stationed. Averaged across the 41.5-km^2 area, significantly more western corn rootworms were collected in traps in corn (2.3 ± 0.3 beetles per day) and soybean (2.0 ± 0.3 beetles per day) than in traps in woods (0.02 ± 0.01 beetles per day) or the tree farm (0.02 ± 0.01 beetles per day; $F = 4.97$, df = 449, $P = 0.0002$). In 1997, 8.6 ± 0.5, 17.1 ± 0.9, 0.6 ± 0.2, and 0.9 ± 0.4 beetles per day were caught in corn, soybeans, woods, and the tree farm, respectively. The number of western corn rootworms collected from soybean-field vial traps was overwhelmingly greater than in cornfields ($F = 35.6$; df = 1,437; $P < 0.0001$) in 1997. The modest 1998 result represents an average population reduction of ≈7.5 times compared with 1997 results.

Spatio-Temporal Variation and Periodicity of Daily Western Corn Rootworm Abundance

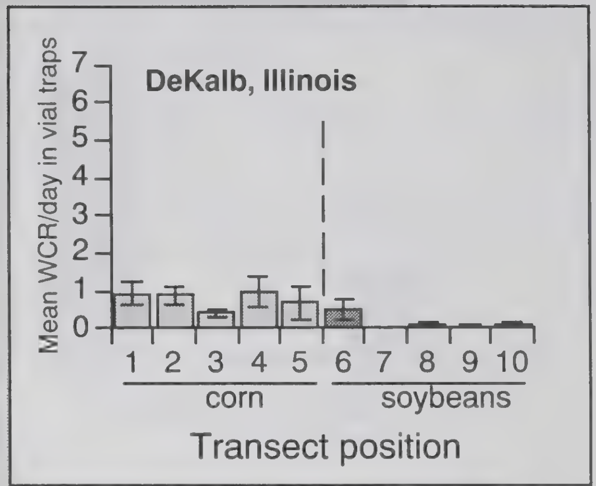
Eight soybean and 7 cornfields located at 5 road intersections across the local monitoring network were selected as sites to study the periodicity of western corn rootworm abundance. Each week, sets of sweep samples (100 sweeps per field) and live collections (5 min) were obtained between 0800 and 0900, 1200 and 1300, 1400 and 1500, and 1900 and 2000 hours from the same area of each corn or soybean field, providing spatial and temporal resolution on western corn rootworm abundance. After collection, beetles were immediately transferred into coolers of dry ice to preserve them for later dissection.

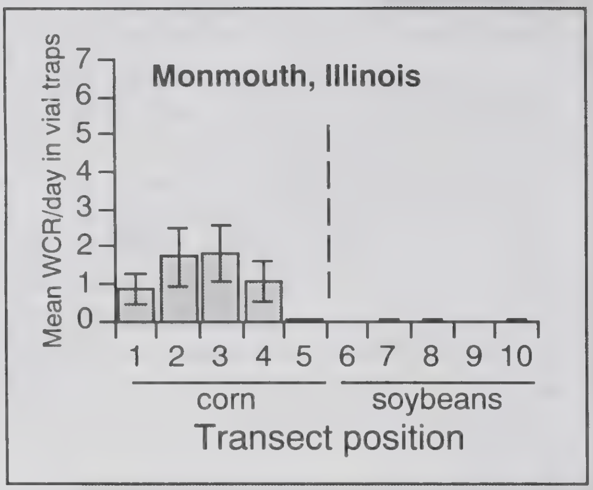
Western corn rootworm abundance in both corn and soybeans varied significantly during the day (Figure 4). In soybeans, western corn rootworm was significantly more abundant in the morning and evening than in midday. In corn, the greatest western corn rootworm abundance occurred in the evening.

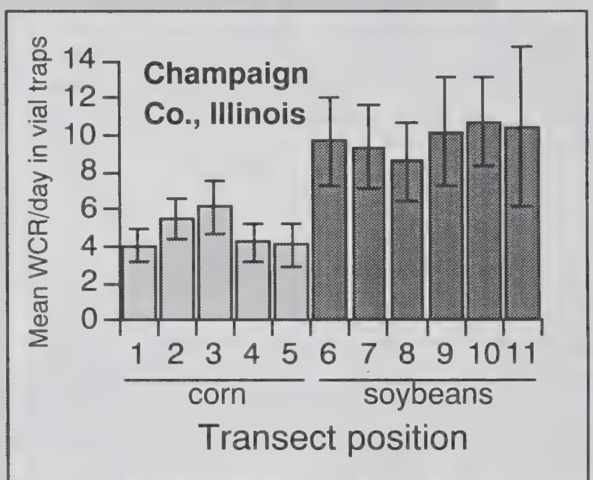
Champaign County Vial-Trap Transects

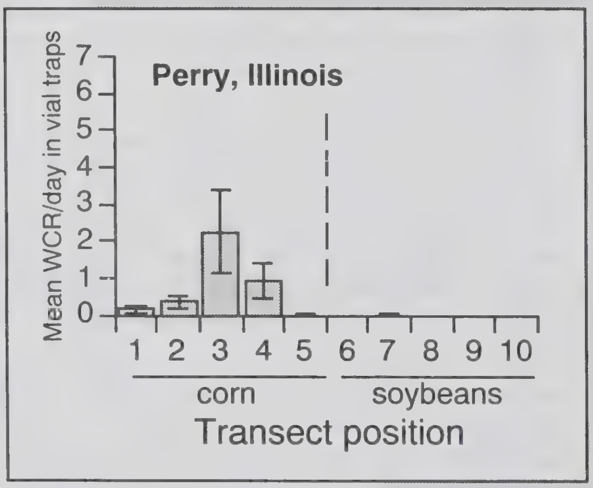
Vial-trap transects were deployed between adjacent first-year corn and soybean (as well as adjacent corn and oats and alfalfa plots) fields at 3 locations in Champaign County (2 northeast of Urbana, 1 northwest of Champaign). A transect consisted of 10 vial traps (5 in corn and 5 in the crop adjacent to corn). Traps were changed weekly at which time the insecticide-treated strips also were replaced. At our primary research and observation site, Lost 40, located northeast of Urbana, traps were changed twice weekly. Vial traps were deployed on 26 and 30 June. A 6th vial trap was deployed in the Champaign field on 8 July.

In addition to the transects, another 66 vial traps were distributed in a grid across 5 of eight 4-acre research plots at the Lost 40 site. Twenty-four vial traps each were distributed in a 4 x 6 grid in a 4-acre soybean field and another field was divided into two 1-acre alfalfa and two 1-acre oat plots. These plots were immediately east of a cooperating grower's first-year cornfield. Transects beginning in this first-year cornfield extended into soybeans, oats, and alfalfa. Six vial traps were placed in









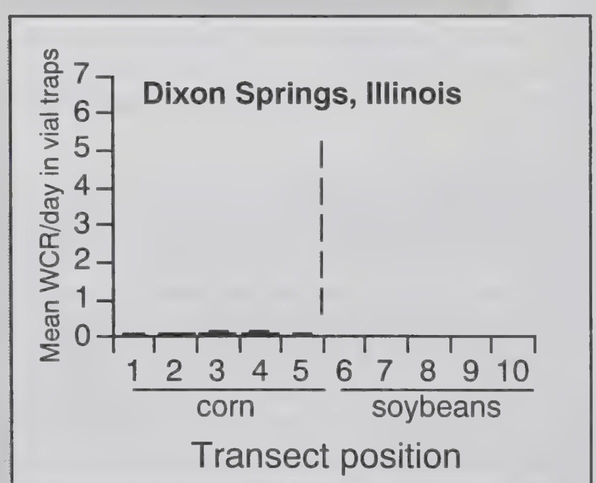


Figure 3 • WCR abundance along corn-soybean transects at five sites in Illinois. Sites other than the Champaign Co. site, were all located at University of Illinois Field Research and Extension Centers and were well outside the WCR problem area. A dashed line marks the corn-soybean field interface. (Note: the Y-axis scale for the Champaign Co. sites is twice that of the other locations).

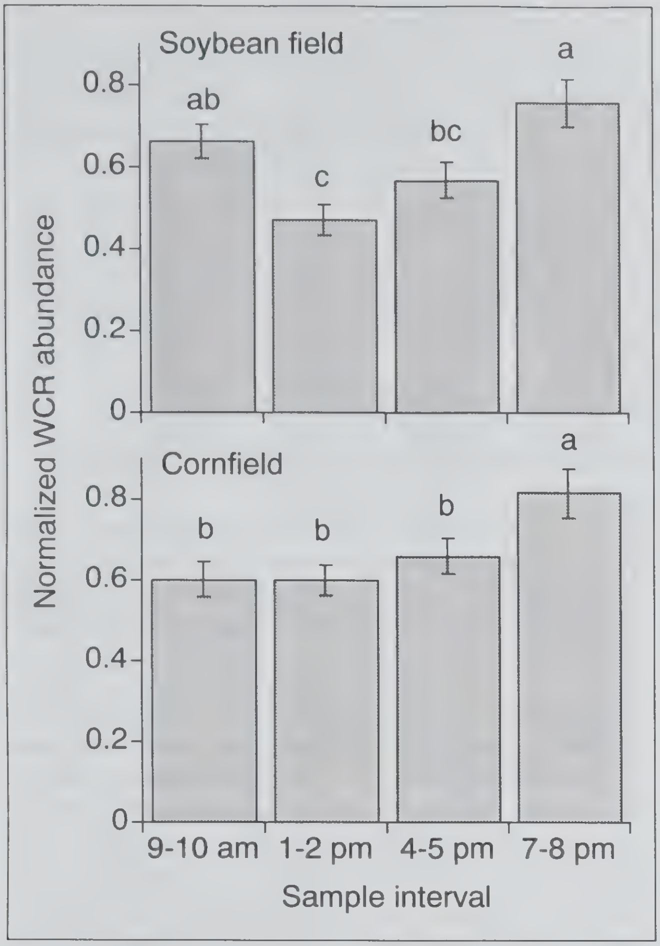


Figure 4 • Daily periodicity of WCR abundance in corn and soybean fields. Sweep samples and live collections were made in 8 soybean and 7 cornfields, respectively, on 7 days between 7/15/98–8/18/98. Each location was sampled four times during the day. Data were normalized (WCR abundance for each interval at a given site was divided by the maximum abundance at the same site on that day) to correct for seasonal variation in WCR abundance. Bars bearing the same letter are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

each of 2 other soybean fields and an alfalfa field. These vial traps were changed twice a week at the time the transects were serviced.

The first male western corn rootworm adults were observed on 28 June. By the end of week 1 (July 5–11), western corn rootworm adults were common in cornfield vial traps (Figure 5). Because these vial-trap data represent beetles captured during the week prior to their retrieval, the timeline of events they depict is shifted later by 1 wk compared with instantaneous measures of abundance (e.g., beetle counts on plants and sweep samples). Between weeks 1 and 6, western corn rootworm abundance in soybeans increased significantly, whereas numbers in corn remained relatively steady. Outside of corn, the percentage of female western corn rootworms increased rapidly with time: by week 2, females comprised ≈65% of all beetles captured; and by week 7, females represented >90% of all beetles collected in vial traps outside of corn. Peak western corn rootworm abundance in soybean vial traps occurred on or around 6 August (week 5). Peak western corn rootworm abundance in oats and alfalfa occurred during week 6. Heavy rains were recorded during week 5, when 31 cm of rain fell at our field site. Conditions

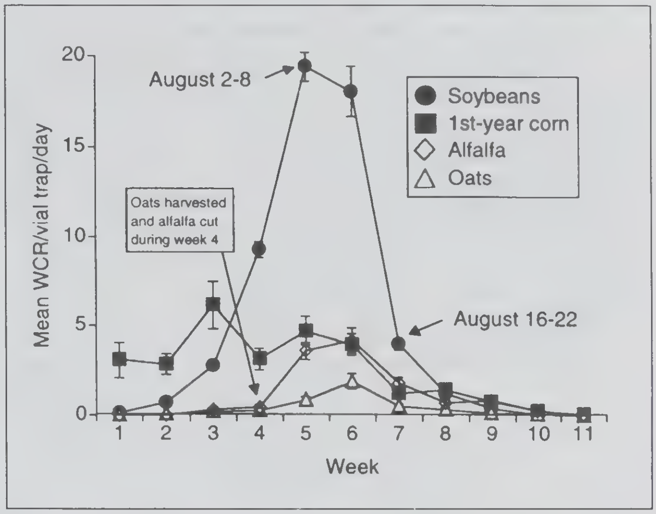


Figure 5 • Weekly adult WCR abundance in vial traps placed in plots of soybeans, first-year corn, alfalfa and oats at the Lost 40 site. Vial traps were emptied twice weekly.

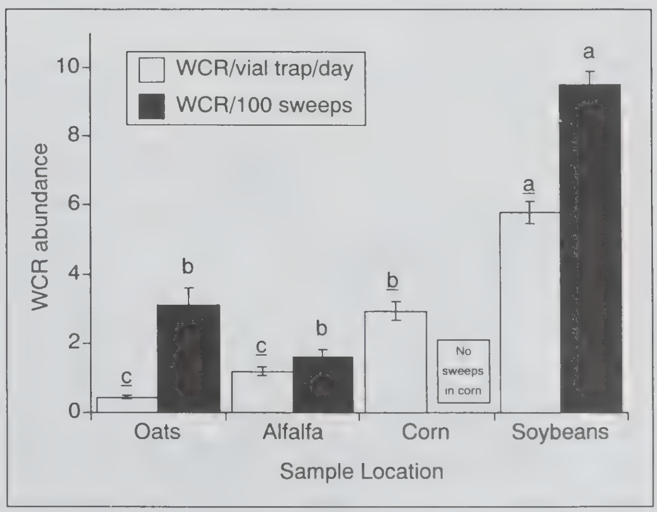


Figure 6 • Mean adult WCR abundance as measured by vial traps and sweep samples in soybeans, first-year corn, alfalfa and oat fields at the Lost 40 site. Bars bearing the same letter within a sampling method are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

remained wet at the field site for several weeks. A high incidence of fungal infection among insects collected from the field at this time suggests disease may have contributed to the general population decline between weeks 6 and 7. Vial traps in soybean caught significantly more western corn rootworm than those in corn, oats, or alfalfa ($F = 81.4$; df = 1,751; $P < 0.0001$) (Figure 6). Although vial traps in corn caught significantly fewer beetles than those in soybeans, they performed significantly better than traps in either alfalfa or oats.

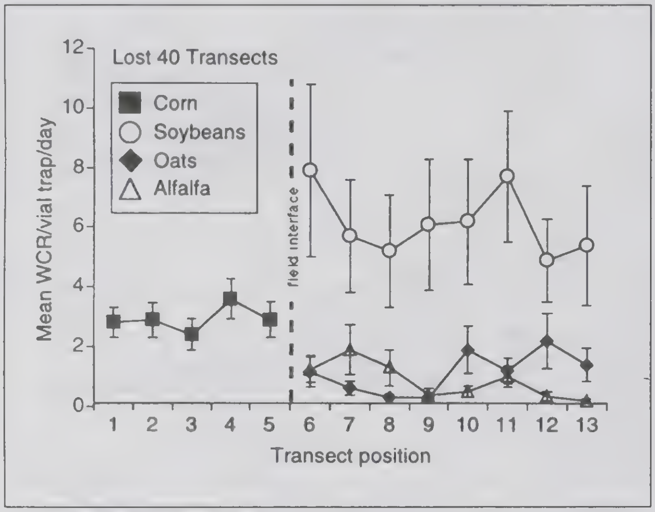


Figure 7 • WCR abundance along three vial trap transects: corn-soybeans, corn-alfalfa, & corn-oats at the Lost 40 site northeast of Urbana, Ill. Vial traps were 30 rows apart in corn and 15 rows (or the equivalent distance) apart in soybeans, alfalfa and oats.

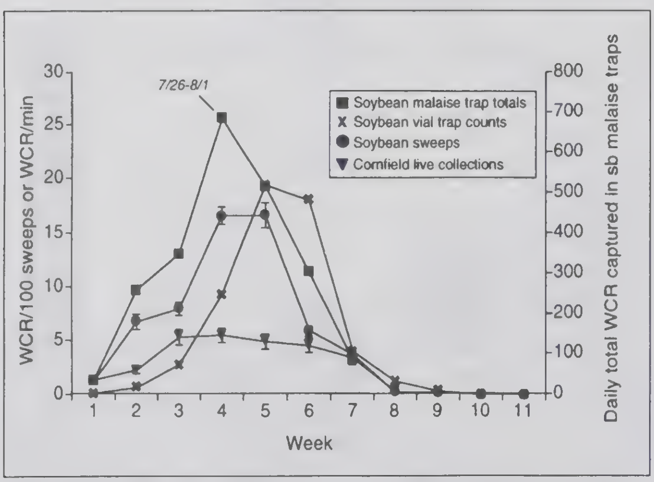


Figure 8 • Seasonal comparison of adult WCR abundance as measured by a variety of methods at the Lost 40 site northeast of Urbana, Ill. Vial trap data appear to lag behind those of the other methods because they provide data from the week previous to their collection.

As observed along other transects in Champaign County (i.e., Lost 40), western corn rootworm was most abundant in soybean-field vial traps (Figure 7). Western corn rootworm also was collected in oats and alfalfa but at a lower rate. Results from the grid of vial traps arrayed around Lost 40 indicate that western corn rootworm abundance was not significantly different in separate plantings of the same crop (soybeans and alfalfa), nor did abundance vary significantly within a plot.

Sweep Samples and Live Collections

Sweep nets and live collection methods were used extensively at the Lost 40 location to monitor western corn rootworm population fluctuations during the 1998 growing season. Extensive sweep sampling in soybeans, oats, and alfalfa and live collections in corn were made throughout the season at this site, multiple times per day, and at multiple locations around the site.

Sweep sample and live collection data corroborated abundance patterns established using vial traps (Figure 8). Sweep samples collected in soybeans indicated that the western corn rootworm population peaked during weeks 4 and 5 and fell by week 6. The same pattern was observed for sweep samples in oats and alfalfa (data not shown). The proportion of females in soybean sweep samples rose greatly from 55 to >84% between weeks 1 and 2, and remained at 85 to 100% female for all subsequent weeks. As observed in vial traps, significantly more western corn rootworms were collected in soybeans than in either oats or alfalfa (Figure 6).

Patterns of western corn rootworm abundance were observed to fluctuate significantly during the day (Figure 9). In general, significantly more western corn rootworm are caught during morning or evening than are caught during midday in soybeans and alfalfa. There were no significant differences in abundance in oats. The proportion of females in plantings outside of corn also declines significantly in the evening (0.75) compared with the proportions in morning (0.88) and midday (0.90) samples.

Similar patterns of western corn rootworm periodicity were observed during the 1997 growing season (Spencer et al. 1998). In 1997, over 20,000 adult western corn rootworms were collected during sweep samples and live collections in the soybean and cornfields at the Lost 40; 2,300 adults were dissected and scored for reproductive development, mating status, and contents of their digestive tract. We found that the reproductive status (a measure of egg development and an indication of the potential for oviposition) of western corn rootworm

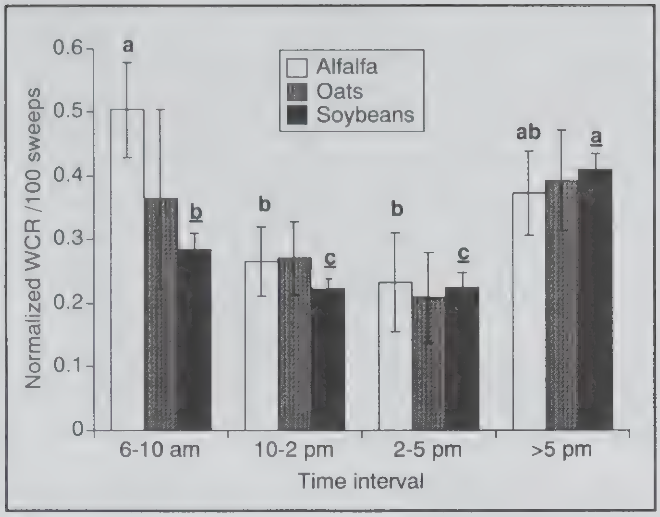


Figure 9 • Daily periodicity of WCR abundance in alfalfa, oats and soybean fields at the Lost 40 site northeast of Urbana, Ill, as measured by sweeps samples over the 1998 field season. Data were normalized (WCR abundance for each planting was divided by the maximum weekly WCR abundance in that planting for 12 weeks) to compensate for seasonal changes in WCR abundance. Bars bearing the same letter within a planting are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

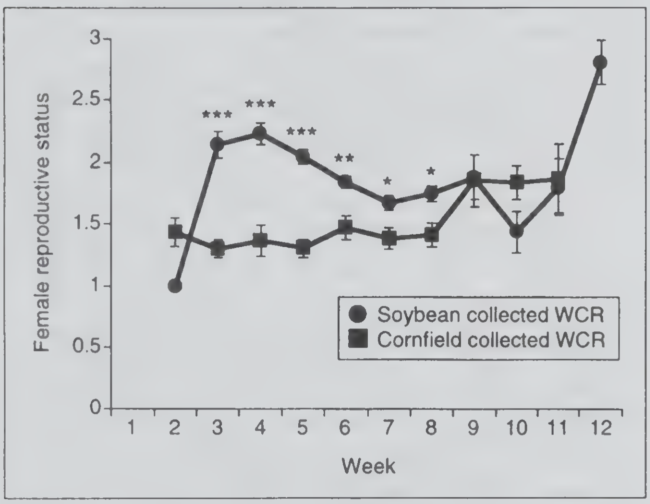


Figure 10 • Seasonal pattern of reproductive status (a measure of egg maturity; 0= no egg development to 4= mature eggs) for female WCR collected in corn and soybean fields during 1997.

females in soybeans was significantly greater than that of females in corn between weeks 3 and 8 (Figure 10); thereafter, females from corn and soybeans had a similar reproductive status.

Based on patterns of western corn rootworm capture in directional malaise traps during 1997, we hypothesized that western corn rootworm is moving frequently between corn and soybeans. Dissections of western corn rootworm collected in 1997 from the fields where movement was monitored revealed that a large proportion of western corn rootworm females had both corn and soybean plant tissues in their digestive systems at the time of capture (Figure 11). The presence of corn tissue in the guts of females collected in soybeans indicates that these individuals had been feeding in both locations within the last hour (it takes ≈1 h for a piece of food to completely pass through and exit the beetle's digestive system). Two peaks of corn and soybean feeding were observed, coinciding with pollen shed and corn pollination in the local cornfields and that of a late-planted cornfield north of our sampling site.

The proportions of females with both corn and soybeans in their digestive tracts closely mirrored daily patterns of western corn rootworm abundance established for the 1997 population (Figure 12). The greatest proportion of corn and soybeans in the gut is found at times when western corn rootworm populations have been observed to be on the move between corn and soybeans. The proportion of males with both corn and soybeans in the digestive tract does not differ significantly over time. The daily patterns of western corn rootworm abundance in soybeans were remarkably similar between 1997 and 1998 (Figure 13).

Malaise Trap Monitoring of Western Corn Rootworm Movement

Malaise traps capture insects flying in or out of fields. In 1998, using 28 malaise traps (20 were in soybeans), we caught only one-tenth as many flying western corn rootworm as we had with one-third fewer traps (8

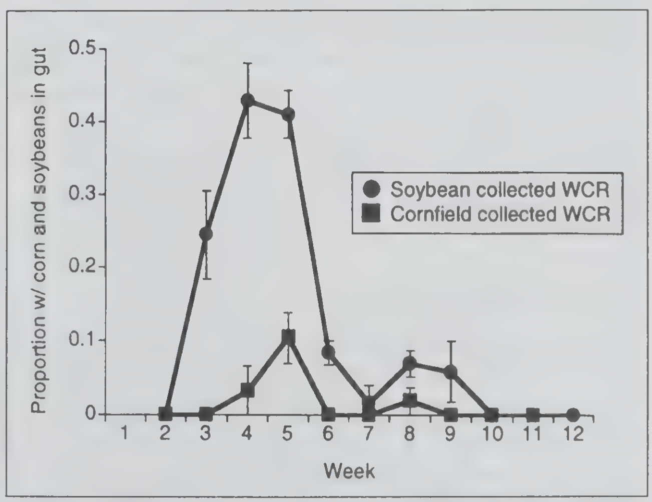


Figure 11. Proportion of female WCR collected from corn and soybean fields in 1997 (n=1155) whose gut contents included both corn and soybean plant parts. The occurence of both corn and soybean tissues in an insect's gut indicates that it had fed in both fields within the hour prior to collection.

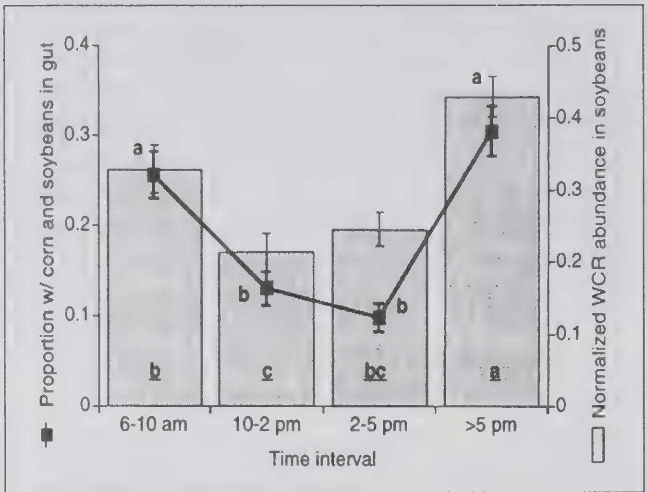


Figure 12 • Daily patterns of corn and soybean presence in the guts of female WCR superimposed on the periodicity of adult WCR abundance in soybeans for 1997. Insects from the sweep samples were dissected and used to generate the periodicity patterns. Bars or points bearing the same letter are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure . $n = 1155$ females.

malaise traps) in 1997, for an overall estimated decline of ≈25 times. The 1998 results for the soybean fields reveal that peak population occurred 21 d earlier in 1998 than it did in 1997 (Figure 14). The week of peak abundance in malaise traps coincided with peak western corn rootworm abundance in soybean sweep samples and cornfield live collections. As in 1997, daily western corn rootworm abundance was highly variable. Traps elevated to 4 or 8 m above the soybean canopy caught significantly fewer western corn rootworms than those within 1 m of the soybean canopy ($F = 44.3$, df = 833, P = <0.0001) (Figure 15). Females made up a significantly greater proportion of the insects trapped in the elevated malaise traps than those at ground level ($F = 4.5$, df = 806, $P = 0.03$) perhaps indicating that females are more likely to engage in flight behavior conducive to long-distance dispersal.

Trécé attractant traps

In addition to vial traps, 4 pairs of Trécé attractant traps (Trécé, Inc., Salinas, CA) were stationed in corn and soybean fields around the 41.5-km^2 vial trap network. The traps consisted of a clear plastic cup bowl with removable rainshield baited with a proprietary floral lure and a block of Sevin-treated insect diet. Traps were mounted on 150-cm-tall PVC poles. Trécé traps were located 30 m from the vial trap in selected fields. A 5th pair of Trécé traps was deployed at the Lost 40 site along a corn–soybean transect. The attractant traps were monitored when vial traps were changed.

Throughout the period when they were deployed, the Trécé traps collected tremendous numbers of western corn rootworm (Figure 16), so many that during peak western corn rootworm abundance, captured western corn rootworm were weighed rather than counted. The Trécé traps accumulated western corn rootworms at a rate that was >40 times that of vial traps in soybeans and 15 times that of vial traps in corn. The trap lures were not changed during the entire summer.

Effect of Insecticide-Free "Slamless" SLAM Application on Western Corn Rootworm Abundance in Soybeans

SLAM is an insecticide developed to specifically target Diabroticite beetle pests and is manufactured by MicroFlo, Inc. (Lakeland, FL). It contains cucurbitacins (behavioral arrestants and feeding stimulants upon which western corn rootworm and other corn rootworms feed compulsively) formulated with the insecticide carbaryl. This combination of components allows much less active ingredient to be used to affect control. SLAM has been applied for adult corn rootworm control in corn and soybeans as part of the Areawide Western Corn Rootworm Management Program for several years (Buhler et al. 1998).

On 20 August, an experiment to evaluate the effect of applying SLAM formulated without insecticide ("slamless-SLAM") (MicroFlo) on western corn

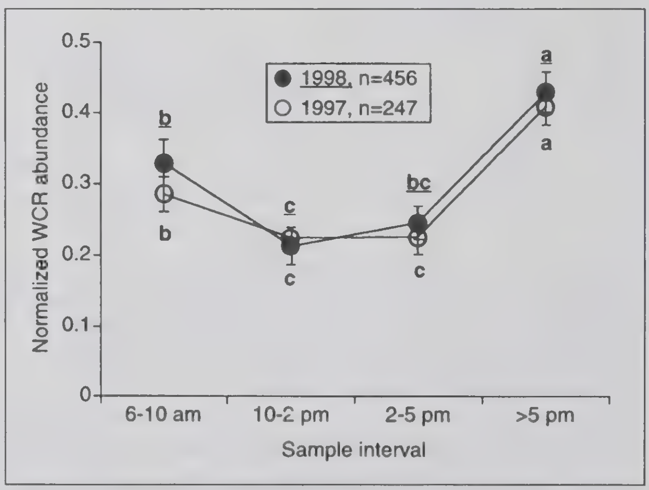


Figure 13 • Daily periodicity of WCR abundance (as measured in sweep samples) in soybean fields at the Lost 40 site during 1997 and 1998. Data were normalized (each measure of WCR/100 sweeps in soybeans was divided by the weekly maximum WCR/100 sweeps in soybeans) to compensate for seasonal changes in WCR abundance. Points bearing the same letter are not statistically different at $\alpha = 0.05$ from others within a year according to Fisher's Protected LSD procedure.

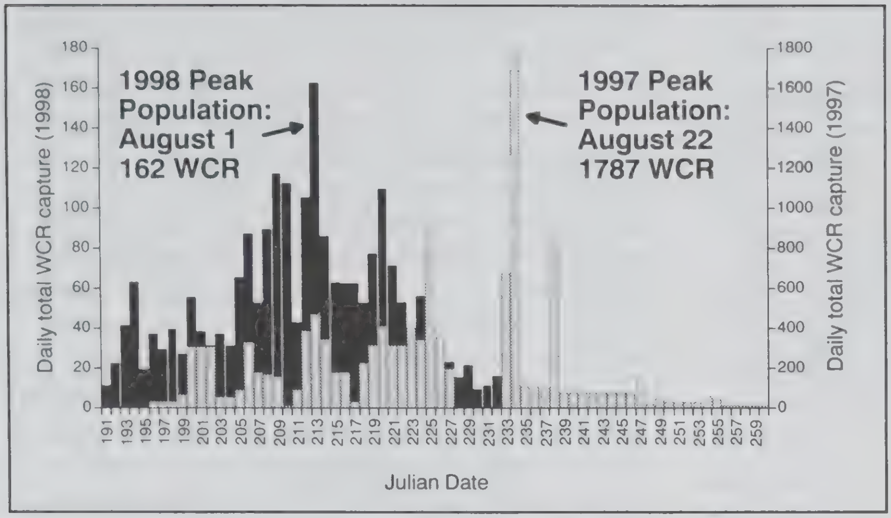


Figure 14 • Daily capture of adult WCR in directional malaise traps positioned around the perimeters of soybean fields during 1997 and 1998. Results for 1997 and 1998 are based on captures in 8 and 20 traps, respectively. Peak 1998 WCR abundance was three weeks earlier than in 1997.

rootworm populations in soybeans was executed. Because soybeans are an inadequate food for western corn rootworm egg production and long-term survival, it may be possible to significantly affect the reproductive potential of female western corn rootworms by enticing them to remain in soybeans for extended periods. We were interested to learn if an application of just the formulated cucurbitacins in SLAM could increase western corn rootworm populations in soybeans (where western corn rootworm feeding damage has no effect on crop yield (Spencer et al. 1997, 1998). Perhaps female western corn rootworm arrested in soybean fields will fail to balance their diet and, as a consequence of reduced health, cease to produce mature eggs.

The slamless-SLAM was applied at the recommended rate of 0.375 lb/acre in sixteen 8 row by 50 ft soybean plots arrayed around all sides of the soybean field at the Lost 40. In preparation, >2,000 adult western corn rootworms were collected from area cornfields and transferred into cardboard containers in groups of 100 beetles. Half of the small plots were hand sprayed with the formulation on the evening of 20 August by using a backpack reservoir and a hand-held 2-row-spanning sprayer equipped with TeeJet 8002VS nozzles operating at 20 psi. After spraying, 2 containers of 100 western corn rootworms were placed in half of the sprayed plots and half of the plots that had not been sprayed. The remaining sprayed and unsprayed plots received no western corn rootworm augmentation. The following morning before sunrise, western corn rootworms were released from the containers. That evening each plot was sampled with a sweep net and the number of beetles was counted.

Significantly more western corn rootworms were recovered from the plots where SLAM had been applied ($F = 8.7$, df = 1, $P = 0.01$) (Figure 17); there was no significant effect of adding 200 western corn rootworms to some plots (F=0.14, P=0.71, df=1) nor any SLAM x western corn rootworm addition interaction ($F = 0.02$, df = 1, $P = 0.89$). In addition, abundance of northern corn rootworm and southern corn rootworm (*Diabrotica undecimpunctata howardii*) also was significantly greater in plots with SLAM (data not shown). The abundance of other non-Diabroticite beetles (e.g., bean leaf beetles and Japanese beetles) in the treated plots was not significantly altered by the treatments. This outcome was to be expected if the effects of treatment were due to the cucurbitacin content of the spray and not to some other factor or disturbance associated with the experiment.

Soybean Cultivar Testing

Consumption of soybean foliage by adult western corn rootworms has been observed in areas where western corn rootworms are a problem in first-year corn. It has been hypothesized that soybean varieties less attractive to western corn rootworm for feeding may be useful for

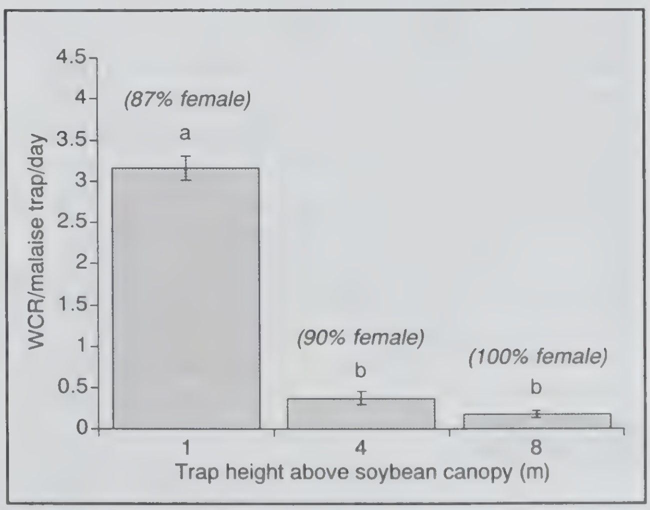


Figure 15 • Relationship between malaise trap height above the soybean canopy and WCR capture rate in 1998. There were 16 traps at 1 m, 2 at 4 m, and 2 at 8 m. Bars bearing the same letter are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

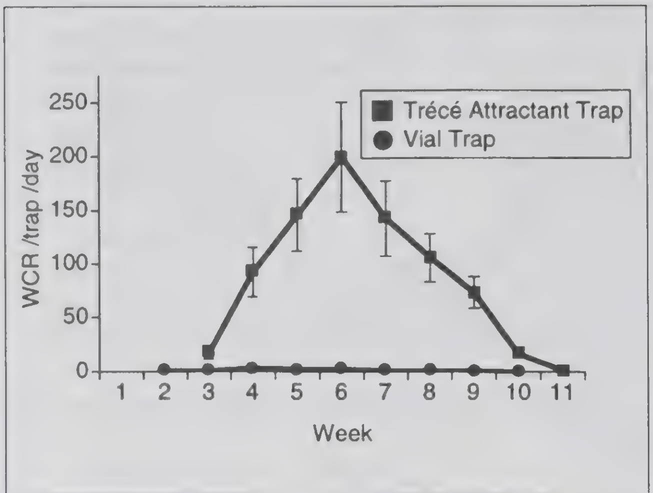


Figure 16 • Comparative collection rates for vial traps and Trécé attractant traps positioned in corn and soybean fields.

reducing oviposition in soybeans by shortening the time females spend in a field. In a laboratory feeding study, 3 Mexican bean beetle (*Epilachna varivestis* Mulsant) resistant soybean varieties ('HC 83-193,' 'PI 229358,' and 'MBB 80-133') along with a Mexican bean beetle-susceptible control ('Elf'), and the western corn rootworm-susceptible 'Williams 82' (a variety shown to be readily consumed by western corn rootworm in previous studies) were presented to single soybean field-collected female western corn rootworm in no-choice tests. Each female was given a single leaf disk (diameter) cut from 1 soybean variety and held for 2 or 3 days in a 20 by 60 mm Petri dish with a moist cotton dental wick. At the end of the experiment, leaf disks were removed from each container and the area consumed was determined. Control leaf disks, prepared just as the test disks and held under identical conditions during the period of insect feeding, were used to make weight-per-unit-area determinations so that leaf area consumed could be standardized across the varieties. All of the Mexican bean beetle-resistant soybean varieties, and the Mexican bean beetle-susceptible control disks were consumed at a significantly reduced rate than that of the susceptible Williams 82 disks ($F = 10.8$, $n = 100$, $P < 0.0001$) (Figure 18).

Discussion

Compared with 1997, western corn rootworm populations in Illinois soybeans were approximately 10-fold lower in 1998. A potentially devastating western corn rootworm problem anticipated for 1998 was probably averted by significant rainfall during the period of peak western corn rootworm egg hatch and larval establishment on corn roots. Western corn rootworm populations were significantly reduced throughout most of Illinois (northern corn rootworm populations also were much reduced across the northern half of Illinois). No new pockets of western corn rootworm infestation in soybeans were identified outside of the counties previously identified as at high or moderate risk for western corn rootworm damage. Statewide, western corn rootworm populations in soybean fields remained greatest within the 9-county problem area identified in 1995. Monitoring at sites remote from the problem area revealed a stark contrast between the situation in east central Illinois and that where the western corn rootworm has yet to arrive.

The numbers of western corn rootworms collected with vial traps in several Champaign County corn and soybean fields indicate that the population decline occurred in both corn and soybean fields. For comparison, during the 1997 growing season, vial traps in corn and soybeans averaged 70–80 western corn rootworms

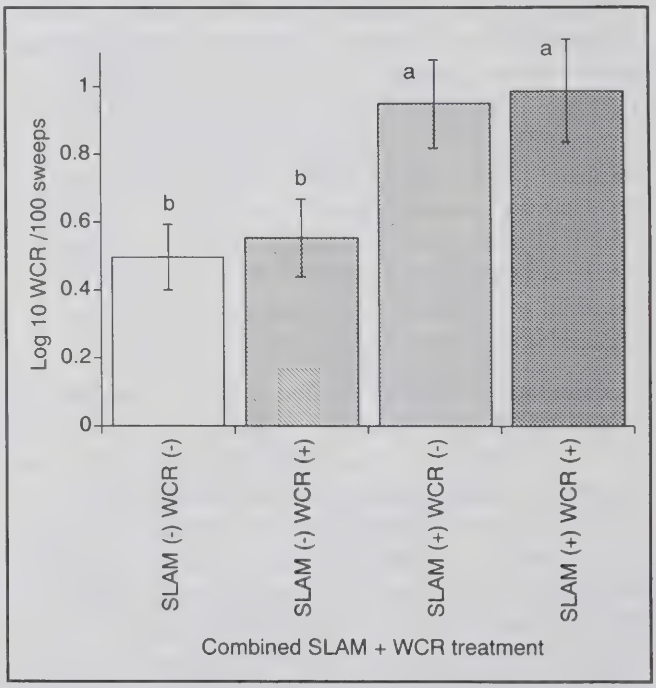


Figure 17 • Effect of SLAM (custom-formulated without carbaryl) and WCR addition on WCR abundance in small soybean plots. SLAM was applied to SLAM(+) plots with a hand sprayer at 0.375 lbs/acre. WCR(+) plots received 200 adults the morning after SLAM (+ or –) treatment. Treatment combinations were replicated 4 times in a factorial design. WCR abundance was $\log_{10}$ tranformed before analysis. Bars bearing the same letter are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

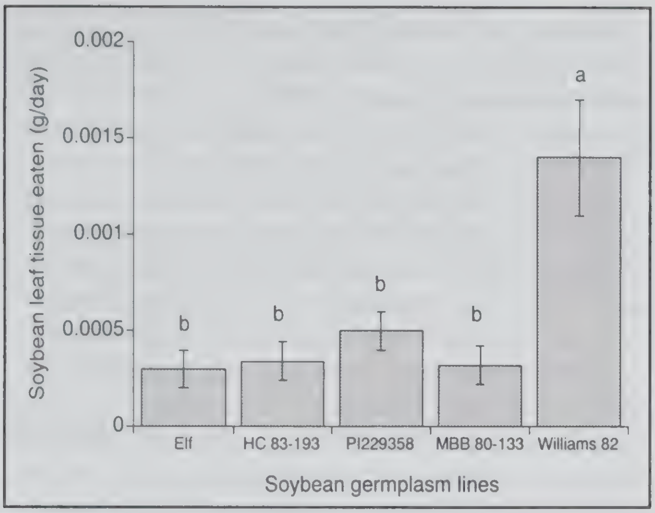


Figure 18 • Consumption of soybean foliage from five soybean germplasm lines by individual adult female WCR in no choice tests ($n = 20$ for each germplasm line). Williams 82 germplasm is a control line readily consumed by WCR adults in east-central Illinois. Germplasm lines HC83-193, PI229358, and MBB 80-133 gave demonstrated resistance to Mexican bean beetle (MBB) feeding. Elf is a MBB susceptible line. Bars bearing the same letter are not statistically different at $\alpha = 0.05$ according to Fisher's Protected LSD procedure.

per day; however, in 1998 the season average for corn and soybeans was only 3.1 and 6.1 western corn rootworm per day, respectively.

Multiple sampling methods indicate that the western corn rootworm population emerged and later peaked ≈2 to 3 wk earlier than in 1997. Patterns of western corn rootworm abundance as measured in vial traps reveal a consistent pattern: western corn rootworms are initially detected in corn and remain most abundant there for ≈3–7 d. Thereafter, western corn rootworm populations build in soybeans and rapidly exceed those in corn. In spite of generally low populations throughout Illinois counties most at risk for western corn rootworm damage in first-year corn, western corn rootworm continued to be abundant in soybean fields.

Dissection of beetles from the 1997 growing season and identification of individuals with both corn and soybean tissues in their gut demonstrate that movement between corn and soybeans (and probably other crops) is extensive during the 1st mo of the western corn rootworm season. This period coincides with a period when reproductive development of females in soybeans is at a peak. We now know that females in soybean fields in the problem area are carrying more mature eggs than those in corn or in corn or soybeans outside the region. An abundance of females in soybeans with high reproductive development early in the season may indicate that significant oviposition in soybeans is occurring early in the growing season.

Western corn rootworm movement between corn and soybeans is occurring according to a consistent schedule. Beetles are most numerous in soybeans during the morning and evening, and numbers are significantly reduced during midday. Based on 1997 malaise trap results, we hypothesized that the daily periodicity of western corn rootworm abundance in soybeans could be explained by movement of between corn and soybeans. Dissection of insects collected during 1997 provides evidence that the periodicity is indeed due to western corn rootworm immigration and emigration between corn and soybean fields.

The origins of the dispersing beetles are revealed by the contents of their guts. The proportion of female western corn rootworms whose guts contained both corn and soybeans simultaneously changes with that of western corn rootworm periodicity in soybeans. At times during the day when immigration to soybeans is suspected to account for the large western corn rootworm populations, a significantly greater proportion of western corn rootworm guts contained both corn and soybeans—a condition that is not possible unless individuals had been in both fields within the previous hour. At midday when movement out of soybeans is hypothesized, the proportion of females with both corn and soybeans in the gut is lowest. Male western corn rootworms display no periodicity in corn and soybean tissues that are present in their gut contents. With respect to feeding on corn tissue and soybean foliage, male and female western corn rootworm behavior is very different.

Although western corn rootworm will feed on soybean foliage and a variety of other plants when not in a cornfield, an exclusive diet of soybean tissue will not support egg development or sustain western corn rootworms for long. The high frequency of western corn rootworm adults that contained both corn and soybean plant tissues at some times of the day and season are evidence of the western corn rootworm's potential to achieve diet mixing that may compensate for the poor quality of a strictly soybean diet. Given the disadvantages of feeding on soybeans, it has been proposed that the soybean plant could be exploited to reduce the likelihood or ability of females to lay eggs in soybean fields. Our western corn rootworm feeding trials, with soybean varieties resistant to the leaf-feeding Mexican bean beetle, indicate that characteristics of these varieties may confer resistance to western corn rootworm feeding. If western corn rootworms are deterred from feeding on soybean foliage, perhaps they will spend less time in soybeans and the females will be less

likely to deposit eggs outside of corn. Conversely, soybean varieties that stimulate excessive feeding, despite the physiological costs, may disadvantage females enough that they suffer reduced reproductive potential as a consequence.

Another approach to managing western corn rootworms would be to arrest it in soybean fields long enough so the costs of not balancing soybean consumption with corn feeding would reduce the ability of females to lay eggs subsequently. The potential for manipulation of movement was demonstrated by using a commercial formulation of the cucurbitacin-based insecticide SLAM, which was specially prepared without any insecticide.

Conclusions

Despite unprecedented high levels of oviposition by western corn rootworm during the 1997 growing season and the mild winter, population densities of western corn rootworm across Illinois counties in 1998 were low. Furthermore, the problem area in the state was not enlarged. Apparently, the heavy rains across Illinois during June 1998 killed large numbers of larvae in many cornfields. It should be noted, however, that scattered pockets of high western corn rootworm abundance were reported, probably where the rainfall was less than elsewhere or on well-drained soils. Low western corn rootworm population densities are good news for Illinois growers; on average, we expect western corn rootworm oviposition in Illinois corn and soybean fields to have been much reduced in 1998 compared with 1997.

Western corn rootworms, like many other insects, have a high reproductive potential. Each female can lay between 200 and 1,000 eggs (Levine and Oloumi-Sadeghi 1991, Gray and Luckmann 1994). With reduced competition among larvae for corn roots next year, a large proportion of eggs deposited in soybean fields during 1998 could emerge as adults in 1999, unless weather conditions are again adverse. Next year, it is likely that some pockets of great abundance will appear in regions with only moderately high western corn rootworm count averages this year. Thus, western corn rootworm management decisions for 1999 should be based on local observations and the use of scouting procedures developed for western corn rootworm in soybean fields (O'Neal et al. 1997, 1998). Western corn rootworm counts were clearly down in numbers but they should not be left out of management decisions.

Hopefully, multiple years will pass before western corn rootworm populations reach the unprecedented high levels like those recorded in 1995 and 1997 (Levine and Gray 1996, Spencer et al. 1998). This paper indicates just how much we have learned about the behavior and physiology of the new western corn rootworm strain that developed in east central Illinois. We suggest that enough progress has been made to allow for development and testing of new tools for managing western corn rootworm in first-year cornfields. We are concerned about the dramatic increase in chemical applications to first-year cornfields for western corn rootworm control in east central Illinois (Pike and Gray 1992, Gray et al. 1998). Fortunately, several biotechnology companies are perfecting genetically engineered rootworm-resistant corn that should be available to Illinois producers in a few years (Kilman 1998). Ultimately, the success and long-term utility of rootworm-resistant transgenic corn will depend on communications between scientists and growers. Sound methods for deploying refugia areas planted with nontransgenic corn will be crucial to the success of this new phase of western corn rootworm control. Learning how western corn rootworm behaves in refugia and transgenic corn plots will be critical to designing appropriate refugia. Consequently, we not only need to develop more environmentally benign tools for controlling western corn rootworm larvae and adults in first-year cornfields right now but also we must explore strategies and tactics for managing refugia populations of western corn rootworm while preserving their susceptibility to transgenics for the not-so-distant future.

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UPDATE ON WESTERN CORN ROOTWORM ON-FARM RESEARCH EFFORTS IN EAST CENTRAL ILLINOIS

Matthew O'Neal, Michael Gray, Kevin Steffey, and John Shaw

As early as the mid-1980s, damage by rootworm (*Diabrotica* spp.) larvae to rotated corn (*Zea mays* L.) (first-year corn) had occurred throughout east central Illinois (Levine and Oloumi-Sadeghi 1991, Steffey et al. 1992). Most larval injury in the mid- to late-1980s was not economic and was attributed to the prolonged diapause of the northern corn rootworm, *Diabrotica barberi* Smith & Lawrence (Steffey et al. 1992) or to a repellency of western corn rootworm (*Diabrotica virgifera virgifera* LeConte) away from pyrethroid-treated cornfields into adjacent soybean [*Glycine max* (L.) Merrill] fields (Levine and Oloumi-Sadeghi 1996). During the early to mid-1990s, dramatic increases in the frequency of western corn rootworm larval damage to corn planted after soybeans reached unprecedented levels (Levine and Gray 1996). There was concern that the extensive and long-term use of crop rotation had selected for a strain of western corn rootworm that could oviposit in soybeans.

In 1996, in response to grower requests for management information, a 3-yr study was initiated to develop an economic threshold for western corn rootworm captured with Pherocon AM yellow sticky traps in soybean fields. These traps have been used to predict rootworm larval injury to continuous cornfields (Hein and Tollefson 1985a). Thresholds have been developed for vial traps and visual counts, but vial traps are not available commercially (Levine and Gray 1994) and visual counts require training and may not be readily practiced by growers.

Hein and Tollefson (1985a) correlated trap counts in continuous cornfields with root injury to corn planted the following year. Correlation of trap counts with injury improved throughout August before decreasing slightly in September, corresponding well with the peak ovipositional period for western corn rootworm in continuous cornfields in Iowa (Hein and Tollefson 1985b). Growers were recommended to use 12 Pherocon AM traps deployed evenly throughout the interior of a cornfield, replacing them weekly during the last 3 wk of August. An economic threshold of 6 beetles per trap per day indicated that a field should be considered at risk for economic injury caused by larvae the following season.

Since 1995, extension entomologists in Illinois have recommended using soil insecticides on corn planted after soybeans for growers in the problem area of east central Illinois, until a threshold could be developed (Gray and Steffey 1998a). An economic threshold would reduce excessive application of soil insecticides. Onstad et al. (1998) predict that this new strain of western corn rootworm will continue to spread east of Illinois and northwestern Indiana into southern Michigan and Ohio. Growers in the affected area are at risk of economic infestations and are in need of a sampling protocol and economic threshold for this new western corn rootworm strain.

In 1998 we presented a preliminary threshold based on Pherocon AM trapping data in soybean fields from 1996 and subsequent root injury ratings from 1997 (O'Neal et al. 1998). Adult beetle counts from soybeans were found to be significantly correlated with subsequent larval root injury. A trapping strategy for growers facing this new strain of western corn rootworm was proposed and has since been used widely by growers in east central Illinois.

We present the results of the 1997 Pherocon AM trapping data in soybeans and the subsequent root injury ratings from 1998. This relationship is compared with that of the 1996 trapping results and the 1997 root

injury ratings. How these most recent findings affect the preliminary threshold presented by O'Neal et al. (1998) is discussed.

Materials and Methods

Study Area

We enlisted 17 growers to take part in the study with farms in the following east central Illinois counties: Champaign (1), Ford (2), Grundy (2), Iroquois (5), Kankakee (1), Livingston (3), and Vermilion (3). All growers had experienced rootworm larval injury to their first-year cornfields in 1995. Growers were asked to plant check strips (no soil insecticide used) in first-year corn and to deploy unbaited Pherocon AM yellow sticky traps (Great Lakes IPM, Vestaburg, MI) in a nearby soybean field.

Trapping Protocol

The following protocol was followed by all cooperators for monitoring their soybean fields with Pherocon AM traps. Sixteen Pherocon AM traps were placed just above the soybean canopy on metal fencing stakes. Traps were replaced every 7 d during a 3- to 4-wk period. In 1996, growers began sampling on the 3rd wk of July; however, sweep-net sampling showed that the peak in western corn rootworm densities occurred after the original 3-wk period selected for monitoring beetle populations. So that the sampling coincided with peak densities in 1997, the trapping period was delayed 2 wk, beginning on 10 August and ending on 31 August. A subset of 6 cooperators agreed to deploy traps an extra week.

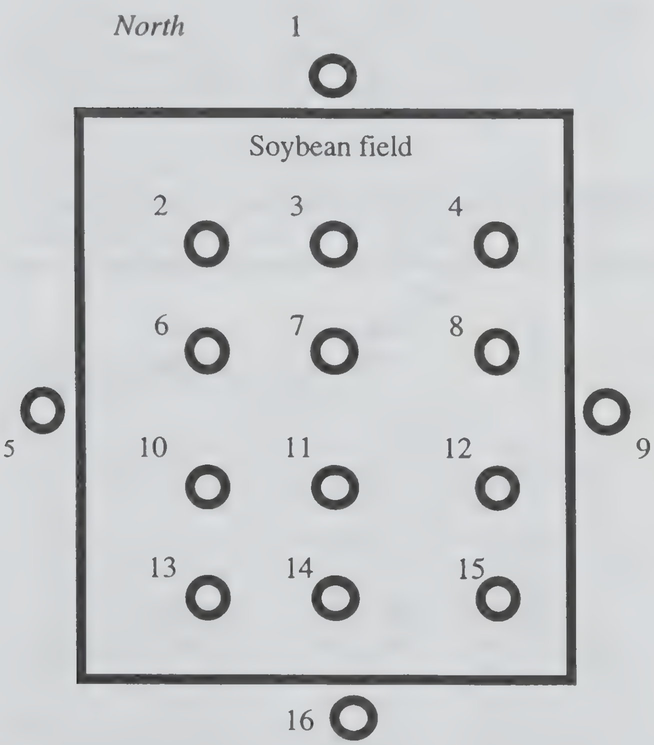

Figure 1 • Array of Pherocon AM traps deployed in a soybean field. The 4 traps numbered 1, 5, 9, and 16 were placed around the perimeter of the field, at the mid-point of each edge, and designated as the exterior 4 traps. The other traps were evenly deployed in the interior and referred to as the interior 12 traps. Traps 2, 4, 13, and 15 are designated as the interior 4 traps. The interior 6 traps is comprised of traps numbered 6, 7, 8, 10, 11, and 12.

Twelve of the 16 traps were placed inside the field in 3 evenly spaced rows of 4 traps each (Fig. 1). The remaining 4 traps were placed around the perimeter of the field, 1 trap on each side in the middle of a field margin. The location of each trap was numbered according to those shown in Fig. 1 and followed by each cooperator. At the end of the growing season, traps were collected from each cooperator and the number of western corn rootworm adults caught per trap per day was determined for each sampling period. The number of females captured was determined for a subsample of 1 to no more than 50 western corn rootworms per trap. Males were separated from females by the shape of the last abdominal sternite under a dissecting microscope (White 1977). In 1997, reproductive development was measured by determining the number of gravid females with mature eggs. Eggs were considered mature if the chorion could be observed under a dissecting microscope.

In 1997, an additional cornfield in Iroquois County was monitored with 14 yellow sticky traps, set up in a similar array but with 2 traps placed on the northern and southern field borders. The traps were placed at ear height, according to procedures described by Hein and Tollefson (1985a). This cornfield was adjacent to a soybean field that also was being monitored with yellow sticky traps.

Root Injury Ratings

The extent of larval rootworm injury was measured in treated (soil insecticide used) and untreated sections of rotated cornfields. In 1996, cooperators were asked to leave 4 untreated check strips (no soil insecticide used) in their first-year cornfields. In 1997 and 1998, cooperators were asked to place 4 check strips in a rotated cornfield that had been a soybean field in which traps were deployed.

Rootworm larval injury was assessed during the first 2 wk of August by digging 15 roots sampled randomly

from the length of 4 alternating treated and untreated strips ($n = 120$ roots per field). A preliminary hypothesis for western corn rootworm oviposition in soybean fields was that gravid females were laying eggs only in field boundaries. To determine if a location effect existed, the location of sampled roots was recorded in 1997 and 1998. Sampled roots were removed from fields, washed, and rated for rootworm larval injury by using the Iowa State University 1 to 6 scale (Hills and Peters 1971): a rating of 1 indicates no visible damage or only a few minor feeding scars; a rating of 2 indicates some roots had feeding scars but none eaten off to within 3.8 cm (1.5 in.) of the plant; a rating of 3 indicates several roots eaten off to within 3.8 cm (1.5 in.) of the plant but never the equivalent of an entire node of roots destroyed; a rating of 4 indicates 1 node of roots destroyed or the equivalent; a rating of 5 indicates 2 nodes of roots destroyed or the equivalent; and a rating of 6 indicates ≥ 3 nodes of roots destroyed.

There has been a general lack of agreement regarding the acceptance of a standard economic injury index. The economic injury index on the Iowa State 1 to 6 root-injury scale has been reviewed and revised (Turpin et al. 1972, Sutter et al. 1991, Gray and Steffey 1998b). Gray and Steffey (1998b) demonstrated that root ratings well below 4 could contribute to economic losses. Very poor growing conditions, such as wet and cool soils during planting followed by high temperatures and drought conditions during pollination, lowered the economic injury index to levels only slightly above a root rating of 2. The relationship between rootworm larval injury and yield is dynamic and clearly affected by environmental conditions and hybrid choice. For the purposes of our study, a root rating of 3 to 4 will be considered the economic injury index. Growers may want to adjust this index, however, accordingly for differing hybrids and growing conditions.

Due to the extremely wet, cool spring in 1996, only 14 producers were able to plant corn and establish check strips. The root ratings from 1996 are not coupled with beetle counts from soybean fields of the previous year, but they are useful both as an index of larval injury for that season and as a comparison with the 1997 season. In 1997, 17 cooperators were able to plant check strips in fields that had been previously monitored with Pherocon AM traps. Wet conditions in 1998 allowed only 15 cooperators to establish check strips.

Statistical Analysis

Root ratings from 1996 and 1997, from treated and untreated strips in first-year corn, were compared using student's t-test. The general linear model procedure was

Table 1 • Mean (± SEM) number of western corn rootworms, percentage of females, and mean number of gravid females collected with Pherocon AM traps in east central Illinois soybean fields.

	1996			1997			
Julian date[a]	*n* (Fields)	Beetle counts[b]	Percentage of females[c]	*n* (Fields)	Beetle counts[b]	Percentage of females[c]	Gravid females[d]
210	13	2.0 ± 0.2	37.7 ± 2.1				
217	16	3.6 ± 0.2	64.0 ± 1.4				
222				1	6.7 ± 0.5	72.8 ± 3.2	2.0 ± 0.4
224	16	5.6 ± 0.3	69.9 ± 0.9				
229				17	10.3 ± 0.4	51.3 ± 0.8	1.0 ± 0.1
231	9	10.5 ± 0.6	64.4 ± 1.4				
236				18	18.6 ± 0.6	60.1 ± 0.9	1.1 ± 0.1
243				18	28.3 ± 1.0	65.6 ± 0.7	1.1 ± 0.1
250				6	12.0 ± 0.7	71.7 ± 1.7	1.5 ± 0.2
257				4	5.2 ± 0.4	83.0 ± 1.3	1.3 ± 0.2
264				2	1.4 ± 0.2	97.2 ± 1.0	0.4 ± 0.1
LSD		0.9	4.2		4.1	4.7	0.5

$P = 0.05$ for LSD of all means in columns.

[a] Julian date on which traps were removed from the field. Traps were replaced every 7 d.

[b] Mean number of beetle counts (male and female) per trap per day from 16 Pherocon AM traps in a soybean field.

[c] Mean percentage of female beetles per 16 Pherocon AM traps in a soybean field per week.

[d] Mean number of gravid females per field per week.

Table 2 • Mean (± SEM) number (male and female), percentage of female, and mean number of gravid female western corn rootworm collected in corn and soybean fields with Pherocon AM traps in Iroquois County, Illinois, 1997.

Julian date[a]	Beetles counts[b]		% Females[c]		Mean no. of gravid females per week[d]	
	corn	soybean	corn	soybean	corn	soybean
229	27.8 ± 3.1	9.6 ± 0.5**	10.4 ± 2.7	51.1 ± 2.1**	0.2 ± 0.1	1.1 ± 0.2**
236	18.8 ± 1.6	21.8 ± 1.6	14.2 ± 3.6	71.0 ± 1.6**	0.3 ± 0.1	1.6 ± 0.4**
243	20.6 ±1.5	38.5 ± 2.3**	31.4 ± 4.9	66.3 ± 1.5**	1.2 ± 0.4	1.8 ± 0.3
250	9.3 ± 0.8	10.2 ± 0.8	48.8 ± 3.5	74.7 ± 2.1**	1.4 ± 0.3	1.5 ± 0.3
257	6.0 ± 0.4	6.7 ± 0.5	61.5 ± 1.5	82.4 ± 1.8*	1.7 ± 0.3	1.1 ± 0.2
264	2.1 ± 0.3	1.5 ± 0.4	90.9 ± 1.1	97.5 ± 1.6	0.7 ± 0.3	0.5 ± 0.2
LSD	4.6	3.3	10.5	5.0	0.8	0.8
Overall means	14.2 ± 1.2	14.7 ± 5.5	42.3 ± 3.4	73.5 ± 1.6**	0.9 ± 0.1	1.3 ± 0.1

$P = 0.05$ for LSD of Pherocon AM trap means.

t – alpha values for Pherocon AM traps (df = 14) are 2.145 for $P < 0.05$ and 2.977 for $P < 0.01$; *, $P < 0.05$; **, $P < 0.01$.

[a] Julian date on which traps were removed from the field. Traps were replaced every 7 d.

[b] Mean (± SEM) number of adult beetles per trap per day, n = 16 Pherocon AM traps per soybean field and 14 traps per cornfield.

[c] Mean (± SEM) percentage of females per trap per week, n = 16 Pherocon AM traps per soybean field and 14 traps per cornfield.

[d] n = 16 Pherocon AM traps per soybean field and 14 traps per cornfield.

used on 1997 root rating data to determine if a pattern existed between root injury and location within a cornfield. The level of correlation between 1997 root ratings in untreated check strips and 1996 mean beetle captures in soybeans are reported using the Pearson correlation coefficient (r). The number and location of traps (Fig. 1) were used in a series of correlations for each of the soybean fields (Fig. 1). The correlative parameters (date, number of traps, total beetle number versus number of females) with the greatest r values were used in subsequent regression analyses.

Results and Discussion

Table 1 summarizes 1996 and 1997 Pherocon AM trapping data from east central Illinois soybean fields. Mean beetle captures did not decrease during the 1996 trapping period. By delaying the trapping period by 2 wk in 1997, the mean beetle captures did decrease after 24–31 August. The 1 wk of overlap between the 2 yr suggests that western corn rootworm densities did not decrease from 1996 to 1997.

The percentage of female western corn rootworms increased every week during both the 1996 and 1997 trapping season (Table 1). Males western corn rootworms first from the soil. The percentage of females increases later in the season. Although the percentage of females increased over time, the number of gravid females found on Pherocon AM traps did not. The mean number of gravid females collected on Pherocon AM traps was constant, about 1 in 50 beetles throughout 1997. This suggests that the traps are not attractive to females looking for an oviposition site.

More female western corn rootworms are found in soybeans than in cornfields (Table 2). Overall, a greater percentage of females was collected in the adjacent corn and soybean field in Iroquois County. A thorough study of western corn rootworm ovipositional behavior in corn and soybean fields has not yet been done; however, trapping data from Iroquois County suggests that western corn rootworm females move out of corn and into soybean, presumably to lay eggs.

Corroborating this observation is the difference in the number of gravid females found in corn and soybean fields in Iroquois County. Overall, the mean number of gravid females found in the 2 fields was similar. During the first 2 wk of the 1997 trapping period, significantly more gravid females were found in the soybean field than in corn. Although the number of gravid females found was very low, their presence suggests that a period of time exists in which western corn rootworm females may find soybean fields more attractive for egg laying than cornfields.

Pherocon AM traps placed around the perimeter of a soybean field can be used to estimate beetle densities in the interior of a field. More beetles were collected around the exterior than the interior of soybean fields (Table 3). Capture means for interior and exterior traps, however, were highly correlated (Table 3). For all 4 wk of the 1996 trapping season, the correlation between interior and exterior Pherocon AM trap means was significant ($r = 0.86$, $n = 16$ soybean fields, $P = 0.001$).

Table 3 • Comparison and correlation analysis (r) for mean Pherocon AM trap captures of western corn rootworm, for traps placed around the exterior (out), at field margins, and within the interior (in) of soybean fields in east central Illinois, 1996 and 1997.

	1996						1997					
Julian date a	n[b]	Trap location[c]	Counts	t (df)	$P > \lvert t \rvert$	r	n[b]	Trap location[c]	counts	t (df)	$P > \lvert t \rvert$	r
210	13	in	1.8 ± 0.7	–2.03	0.0461							
		out	2.8 ± 0.5	(62.4)		0.77**						
217	16	in	3.3 ± 0.2	–1.98	0.0509							
		out	4.5 ± 0.6	(83.3)		0.81**						
222							1	in	6.6 ± 0.7	–0.32	0.7576	
								out	7.0 ± 0.8	(7.2)		NA
224	16	in	5.1 ± 0.2	–2.61	0.0108							
		out	7.1 ± 0.7	(80.0)		0.91**						
229							17	in	9.9 ± 0.4	–1.72	0.0893	
								out	11.4 ± 0.8	(100)		0.88**
231	9	in	9.4 ± 0.5	–2.33	0.0247							
		out	13.6 ± 1.7	(41.6)		0.76**						
236							18	in	17.6 ± 2.1	–2.52	0.0134	
								out	21.7 ± 1.5	(97.3)		0.87**
243							18	in	26.6 ± 1.0	–2.66	0.0092	
								out	33.6 ± 2.4	(94.2)		0.87**
250							6	in	10.7 ± 0.6	–2.72	0.0113	
								out	16.1 ± 1.9	(26.9)		0.65
257							4	in	4.7 ± 0.4	–1.54	0.1440	
								out	6.7 ± 1.3	(16.2)		0.27
264							2	in	1.2 ± 0.1	–1.13	0.3003	
								out	2.1 ± 0.8	(6.4)		NA

[a] Julian date on which traps were removed from the field. Traps were replaced every 7 d.

[b] The number of soybean fields included in t -test and correlation coefficient analysis.

[c] Interior (in) means from 12 traps, placed within a soybean field in 3 rows of 4 traps per row. Exterior (out) means from 4 traps placed on the margins of a field, 1 trap in the middle of each field border (see Fig. 1).

A combination of all 7 wk of the 1997 trapping season produced a similarly high level of correlation ($r = 0.91$, $n = 16$ soybean fields, $P = 0.001$).

Despite the relatively large densities of western corn rootworms in 1997, root injury to rotated (first-year) corn was relatively low in 1998 (Table 4). Overall, root injury to first-year corn in east central Illinois was lower in 1998 than in 1997. The increase in western corn rootworm larval injury in both treated and untreated strips from 1996 to 1997 did not continue into 1998. In 1998, only 3 cooperators experienced an increase in injury.

The total mean rainfall for east central Illinois is reported in Table 5 for April through June 1996–1998. Western corn rootworm egg hatch begins in late May and can continue through mid-June, making this a critical period for larval establishment. Riedell and Sutter (1995) reported that larval feeding decreased in field plots manually infested with western corn rootworms where precipitation had been excessive. They concluded that increased western corn rootworm larval mortality occurred when soils were saturated. So, it is not surprising that the 2 wettest springs (1996 and 1998) had very similar mean root ratings.

As mentioned previously, 3 cooperators saw an increase in root injury in 1998. They planted earlier than most of the other cooperators in our study and did not have to replant corn due to saturated soil. Thus, in fields where precipitation was not a factor, root injury did occur.

Relationship between Beetles Captured in Soybeans and Subsequent Injury to First-Year Corn

In 1997, the high level of root injury was significantly correlated with 1996 trapping data. Three of the 4 wk in which Pherocon Am traps were deployed in soybean fields were significantly correlated with subsequent root injury (Table 6). The relationship between the 1998 root injury with the 1997 trapping data was not as strong

Table 4 • Mean root ratings of larval rootworm injury to first-year cornfields in 7 east central Illinois counties.

County	1996 treated	1996 untreated	1997 treated	1997 untreated	1998 treated	1998 untreated
Kankakee	NA	NA	2.17 ± 0.08	2.86 ± 0.10	1.62 ± 0.10	1.97 ± 0.09
Livingston						
Field 1	2.08 ± 0.05	2.03 ± 0.06	2.27 ± 0.06	3.17 ± 0.10	2.28 ± 0.09	3.03 ± 0.12
Field 2	2.10 ± 0.05	2.68 ± 0.05	2.00 ± 0.08	2.62 ± 0.13	2.46 ± 0.11	3.10 ± 0.13
Field 3	NA	NA	2.49 ± 0.08	3.04 ± 0.06	NA	NA
Grundy						
Field 1	1.33 ± 0.06	1.27 ± 0.06	1.98 ± 0.06	2.27 ± 0.06	1.55 ± 0.07	1.70 ± 0.08
Field 2	1.50 ± 0.07	1.56 ± 0.06	2.20 ± 0.09	2.40 ± 0.10	2.18 ± 0.09	3.30 ± 0.14
Ford						
Field 1	NA	NA	1.98 ± 0.11	2.63 ± 0.12	1.75 ± 0.06	1.88 ± 0.05
Field 2	NA	NA	3.73 ± 0.12	4.93 ± 0.12	1.52 ± 0.08	2.28 ± 0.17
Field 3	1.85 ± 0.08	2.27 ± 0.13	2.35 ± 0.11	3.27 ± 0.16	2.13 ± 0.10	4.37 ± 0.18
Field 4	NA	NA	NA	NA	1.77 ± 0.06	3.15 ± 0.14
Iroquois						
Field 1	1.74 ± 0.08	1.97 ± 0.11	2.18 ± 0.06	3.09 ± 0.14	NA	NA
Field 2	2.07 ± 0.03	2.33 ± 0.09	2.45 ± 0.09	3.73 ± 0.11	1.83 ± 0.08	3.88 ± 0.17
Field 3	2.08 ± 0.05	2.93 ± 0.14	2.35 ± 0.06	4.50 ± 0.10	1.68 ± 0.07	2.78 ± 0.12
Field 4	2.22 ± 0.06	3.03 ± 0.12	2.74 ± 0.19	4.02 ± 0.15	1.67 ± 0.12	3.17 ± 0.20
Field 5	1.83 ± 0.09	2.28 ± 0.15	NA	NA	NA	NA
Vermilion						
Field 1	2.10 ± 0.05	3.25 ± 0.05	2.90 ± 0.13	4.13 ± 0.15	NA	NA
Field 2	1.38 ± 0.07	1.48 ± 0.08	2.25 ± 0.06	3.69 ± 0.13	2.31 ± 0.07	3.44 ± 0.21
Field 3	2.05 ± 0.03	2.07 ± 0.03	3.86 ± 0.12	4.28 ± 0.10	1.40 ± 0.08	2.04 ± 0.12
Champaign	2.17 ± 0.11	2.33 ± 0.13	2.37 ± 0.09	3.16 ± 0.11	1.58 ± 0.08	2.14 ± 0.11
Average	1.89 ± 0.08	2.25 ± 0.16**	2.49 ± 0.13	3.40 ± 0.19**	1.85 ± 0.09	2.82 ± 0.20**

T -alpha value for 1996, 1997, and 1998 root ratings (df = 1,305; 1,760; and 1,581; respectively) is 2.576 for $P < 0.01$; ** $P < 0.01$.

Ratings are for corn roots (60 roots per treatment) dug from treated (soil insecticide used) and untreated strips.

(Fig. 2). None of the 4 wk of the 1997 trapping data, alone or combined, could significantly explain any of the larval injury to first-year corn in 1998.

We believe the precipitation from April through June prevented successful larval establishment on corn roots. Standing water and delayed planting undoubtedly prevented larvae from injuring roots at levels suggested by 1997 trapping data. Had western corn rootworm larvae been able to establish in drier soil conditions, similar to those of 1997, the relationship between 1997 trapping data and 1998 root injury may have been more evident.

The relationship between western corn rootworm captures (1997) on Pherocon AM traps and subsequent larval injury (1998) is shown in Fig. 3. Removing the 2 sites with the greatest root ratings in 1998 did not significantly improve this relationship ($R^2 = 12$, $n = 13$, $P > 0.25$). Interestingly, using the mean number of gravid females per trap did not improve the relationship between beetle counts and root injury ratings. Combining these 2 sets of data also did not improve the relationship between trap counts and root injury ($R^2 = 0.013$, $n = 30$, $P = 0.55$).

Economic Threshold for Western Corn Rootworms in Soybeans

Because of the poor relationship between our 1997 trapping data and the 1998 root ratings, we will continue to recommend the economic threshold constructed from 1996 trapping data and 1997 root ratings. We had hoped to reduce the recommended number of traps to as few as 4 traps placed around the edge of a field. Correlations between the 4 exterior and 12 interior traps demonstrated that Pherocon AM traps placed around the outside of a soybean field can be used to estimate beetle densities in the interior of a field. Because the threshold cannot be improved with 1997 and 1998 data, we cannot recommend the use of fewer

Table 5 • Precipitaion totals (centimeters) for a seven county area of east central Illinois for the months of April–September 1996–1998.

Month	1996	1997	1998
April	7.8	4.7	11.2
May	18.9	10.7	9.7
June	11.2	14.4	21.9
Total	13.4 ± 0.5	7.2 ± 0.4	12.8 ± 0.7

East central Illinois precipitation data obtained from the Midwestern Climate Center, Illinois State Water Survey, Champaign, IL.
Counties included within east central Illinois: Champaign, Ford, Grundy, Iroquois, Kankakee, Livingston, and Vermillion.

than 12 traps. Traps should be deployed from the last week of July through the 3rd wk of August, with traps replaced weekly. The total mean trap count for the entire 4-wk period should be used to calculate beetle densities within a soybean field. An economic threshold of 7 beetles per trap per day may result in a root injury rating of 4.0 (1 node of roots destroyed). Two beetles caught per trap per day may result in an average root injury rating of 3.0 the following season. Certain corn hybrids may show a yield loss during poor growing seasons from root injury ratings as low as 2.0 (minor root scarring).

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Table 6 • Correlation coefficients (*r*) for total (male and female) adult western corn rootworm counts from Pherocon AM traps in soybeans and subsequent larval damage to first–year corn.

1996 beetle counts and 1997 root injury						1997 beetle counts and 1998 root injury					
Sampling period	No. of fields	Number of Pherocon AM traps 16	12	6	4	Sampling period	No. of fields	Number of Pherocon AM traps 16	12	6	4
22–29 July	14	0.56*	0.55*	0.54*	0.47	10–17 Aug.	14	0.21	0.21	0.11	0.31
29 July–5 Aug.	17	0.71**	0.72**	0.73**	0.67**	17–24 Aug.	15	0.17	0.16	0.11	0.21
5–12 Aug.	17	0.49*	0.51*	0.49*	0.49*	24–31 Aug.	15	0.22	0.23	0.23	0.23
12–20 Aug.	9	0.29	0.28	0.23	0.32	31 Aug–6 Sept.	5	–0.11	0.06	0.20	–0.01
Total											
4 wk combined		0.64**	0.65**	0.64**	0.64**			0.18	0.20	0.19	0.21

* P < 0.05; ** P < 0.01.

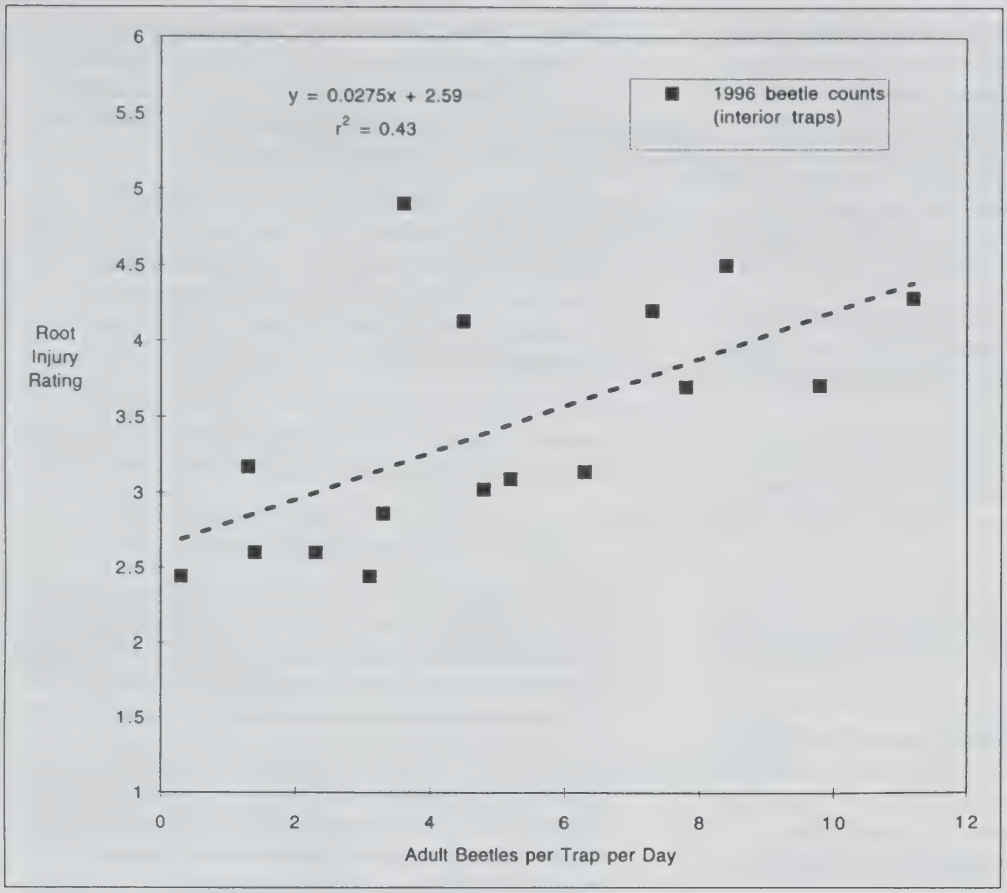
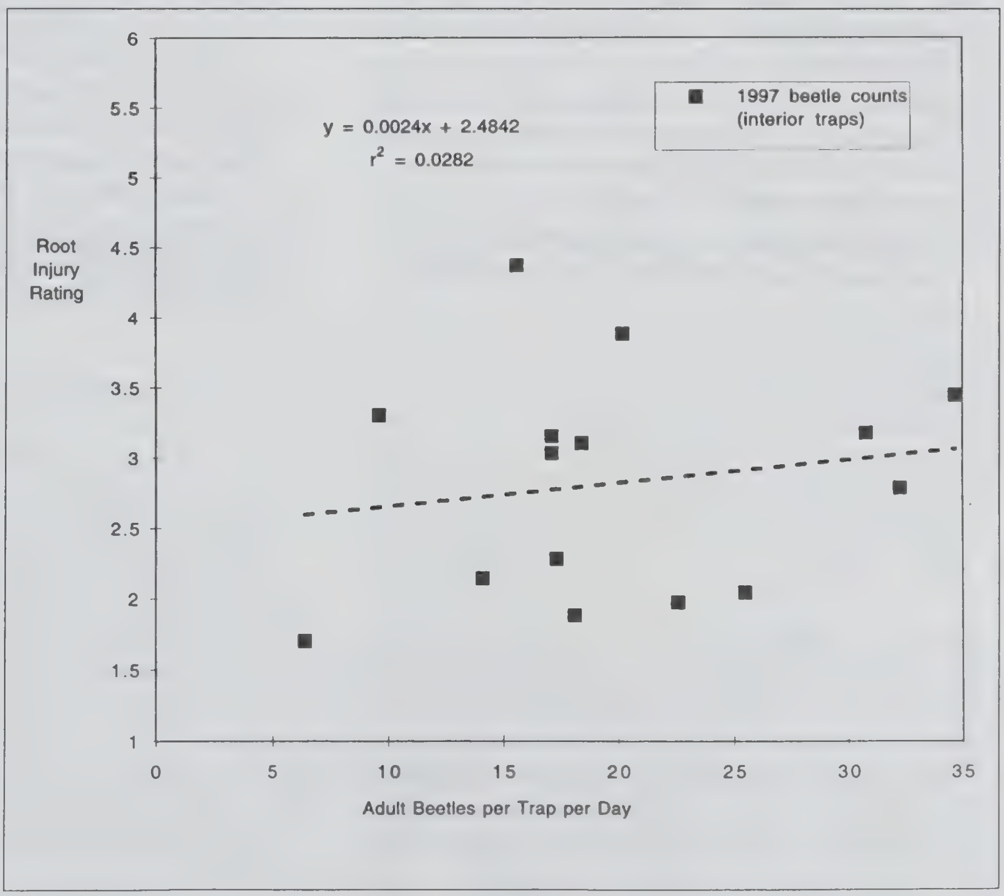


Figure 2 • Relationship between the mean numbers of western corn rootworms (males and females), caught with 12 Pherocon AM yellow sticky traps in soybean fields during 1996, and subsequent larval damage to first-year corn in 1997.

Figure 3 • Relationship between the mean numbers of western corn rootworms (males and females), caught with 12 Pherocon AM yellow sticky traps per day in soybean fields during 1997, and subsequent larval damage to first-year corn in 1998.



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AREAWIDE MANAGEMENT OF CORN ROOTWORMS: WAS 1998 A SUCCESS?

Corey Gerber, C. Richard Edwards, Larry Bledsoe, Michael Gray, and Kevin Steffey

The Corn Rootworm Areawide Pest Management (AWPM) Program is a coordinated effort that links a group of producers together with crop consultants, applicators, and university and government researchers to manage the western corn rootworm, *Diabrotica virgifera virgifera* LeConte, over a large, well-defined area. The summer of 1998 marked the 2nd year of this 4-yr study.

This study has been designed to test the feasibility of using the areawide concept in the eastern Midwest for managing the western corn rootworm. In the study area, unlike the other midwestern areawide management study sites, western corn rootworm apparently has adapted to the corn–soybean rotational system. This development virtually eliminates crop rotation as an effective tool for managing western corn rootworm. The areawide rootworm management concept is based upon the semiochemical insecticidal-bait Slam® (Microflo) as the primary rootworm management tool.

The Illinois–Indiana Study Site

The study site has been established as a 16-mi² area located southeast of Sheldon, IL, and west of Raub, IN. This location was selected based on the close proximity to the institutions (University of Illinois and Purdue University, respectively) coordinating the study, as well as being located in the heart of an area in which rootworm beetles have exhibited a dramatic change in behavior by laying eggs in soybean [*Glycine max* (L.) Merrill] fields.

This program enlists the partnership of >45 growers and ≈11,000 acres of corn (*Zea* mays L.) and soybeans. Nearly 9,500 acres can be treated with Slam® whenever populations of rootworm beetles exceed certain levels in corn and soybean fields.

For additional information relating to the description of the Illinois–Indiana study site, refer to Buhler et al. (1998).

The Year in Review

In general, growers in the areawide site follow a corn–soybean rotation and practice conservation tillage on all their acres. Of the 9,500 acres in the area to be treated with Slam®, there were 83 cornfields (5,200 acres) and 80 soybean fields (4,300 acres). Seven growers had livestock and managed 8 alfalfa fields within the study site. The 10 corn and 10 soybean fields that comprised the untreated (control) fields, along the borders of the areawide site, totaled 1,300 acres.

Growers experienced the usual year of unusual weather in 1998. Unfavorable conditions in the spring allowed for late planting of corn and soybean. A period of heavy rainfall resulted in excessive ponding and loss of crops in some areas. A few of the drowned-out areas were replanted. Due to the hot and dry conditions during August and September, corn and soybean matured much earlier than normal, which resulted in an early harvest.

Sampling for adult western corn rootworm in corn and soybean was conducted for 7 wk; beginning July 13 and ending August 28. Western corn rootworm populations in corn were sampled by counting the number of beetles infesting 2 plants ≈3–5 ft apart in each of 10 locations within a field. Insect populations were estimated in soybean fields by using Pherocon AM® yellow sticky

cards. Sticky cards, distributed through a field in 2 rows of 4 cards, were positioned so that ½ the card was above the soybean canopy. New sticky cards were placed in the field immediately after cards that had been in the soybean field for 1 wk were removed for beetle trap catch.

The decision to treat for western corn rootworm beetles was based on economic thresholds that are well-established in corn (0.5 beetles per plant in 1st-year corn, 0.7 beetles per plant in continuous corn, and at least 10% of the female beetles being gravid), and were arbitrarily determined in soybean (2 beetles per sticky trap per day). Sampling for western corn rootworm in corn ended whenever 10 beetles were counted in 1st-year corn and 14 beetles were counted in continuous corn. The threshold for adult western corn rootworm in soybean, as it relates to the threat of economic injury caused by larvae in corn the following year, is not yet known. The threshold we used in soybean, however, should be low enough to prevent significant oviposition from occurring in these fields. Given the population levels of western corn rootworm in soybean observed in the last several years, it probably would be impractical to economically manage western corn rootworm by using a threshold lower than 2 beetles per sticky trap per day.

Field surveys in Illinois and Indiana in 1997 revealed very large numbers of western corn rootworm adults in both corn and soybean fields. Therefore, we anticipated significant amounts of rootworm larval damage in both corn planted after corn and corn planted after soybeans in east central Illinois and northern Indiana in 1998. Although samples taken early in the spring, shortly after planting in 1998, revealed large numbers of rootworm larvae in the root zone, our evaluations of the adult population through sampling methods in July and August revealed low numbers of adults. We suspect that many young rootworm larvae drowned in saturated soils (due to persistent and copious rains in late May and June). We also suspect that many larvae died of starvation because corn was planted late relative to egg hatch and because of delayed corn root growth due to the saturated soils.

Western corn rootworm beetles were first observed in cornfields around the areawide site on June 30. The first application of Slam® was made to 4 cornfields and 1 bean field on July 21. Shortly thereafter, the number of cornfields requiring treatment rose significantly; however, the number of bean fields requiring treatment remained fairly low and steady. Because of this trend, we needed to ensure that we would have enough Slam® to use on soybean fields later in the year to protect the 1st-year cornfields in 1999. Thus, from July 23 to the final spray date, August 26, only cornfields located ≈1 mi or less from the edges within the Slam® area (managed area) were treated if a threshold of 2 beetles per plant was achieved. All other cornfields (as well as soybean fields) retained the original threshold level. The treatment rate for Slam® was ⅜-lb formulation per acre in 1 gal of water. Windbrake® drift retardent was added to Slam® at a rate of 12 oz/100 gal of spray solution. Slam® treatments during this time appeared to be efficacious in corn. Within 15 h posttreatment virtually all rootworm beetles were dead.

After 1 mo of applications, we had used nearly 1,025 lb of Slam®, applied at the rate of ⅜ lb per acre compared with using nearly 5,900 lb of Slam®, applied at rates of ⅜ or ½ lb per acre in 1997. Western corn rootworm populations escalated during the 3rd wk in August in soybean as corn began to dry down. During the last week of August, beetle numbers crashed.

Final statistics for 1998 showed that of the 159 fields in the treated zone, 67 received at least one chemical application. In these 67 fields, 71 applications were made. Of the fields receiving treatments, 63 fields were treated once and four twice. Out of the 67 fields, 3 fields were treated with Penncap-M®, provided by Elf Atochem, Inc. Thirty-seven soybean fields were not treated due to low levels of western corn rootworm adults. Two aerial applicators logged 4,332 acres of beetle-control flights.

To determine the effectiveness of Slam® as well as the other insecticides used in the areawide program in 1997, we needed to evaluate corn roots for rootworm larval damage in 1998. At the end of July, 2 platoons of root-digging entomologists from Purdue University and from the University of Illinois attacked 46 cornfields in and around the areawide site. Thirty-one fields, found within the managed area, contained 1 or 2 untreated check strips. Nine fields also found within the managed area had no soil insecticide applied at planting. On the outside of the managed area, 5 fields contained 1 or 2 untreated check strips, where one of the fields was left untreated.

The average of means for rootworm larval damage (based on the Iowa State University 1–6 root-rating scale) within the managed area was 1.85 in treated strips and 2.18 in untreated strips. Outside of the managed area, the average root rating was 2.63 in treated strips and 3.11 in untreated strips. The untreated fields within the managed area had an average of 1.99 compared with the single untreated field outside of the managed area, which had an average of 2.67. The preliminary results

suggest that spraying may have had a slight impact on the adult beetle population in 1997.

Root ratings in research trials and in the areawide corn rootworm management study site were lower than we expected, even in check fields that were not sprayed last year for control of rootworm beetles and that were not treated in the spring with soil insecticides. Therefore, we urge caution when these data are interpreted. Although densities of rootworm beetles in fields in the study site were high in 1997 and root ratings from fields in the study site were relatively low in 1998, mortality of rootworm larvae in saturated soils in 1998 partially accounts for the low root ratings.

Plans in 1999

Aspects of the Illinois–Indiana Areawide program should remain the same for 1999. Although altered thresholds were used in 1998, we will attempt to retain and use the original thresholds next season.

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NOVEL FORMULATIONS FOR CORN ROOTWORM INSECTICIDES

M. R. McGuire and R. W. Behle

In an effort to help protect the environment, the United States Department of Agriculture promotes the development of effective pest-control strategies that reduce the amount of pesticide used. The areawide management of adult corn rootworms (*Diabrotica* spp.) is directed at achieving this goal. Currently, fields planted to continuous corn (*Zea mays* L.) receive a prophylactic application of soil insecticides regardless of the infestation level of rootworms. The areawide management strategy uses pest scouting to identify and apply insecticides to fields that exceed the economic threshold for rootworm adults. By controlling rootworm adults this year, the need for planting-time insecticide application next year to fields with unknown pest levels is prevented. The success of this areawide project depends on the selection of an adult insecticide capable of providing season-long control of beetles with a single application. Successful management of corn rootworms by areawide management should reduce the amount of insecticide applied throughout the area while providing adequate control of corn rootworms.

Control measures against the adult stage of the corn rootworm have been practiced since the 1960s. The concept of adult rootworm control is to maintain the number of beetles at a low level to reduce the number of overwintering eggs in the field. Fewer eggs result in fewer larvae to feed on the corn roots the next year. Thus, the major form of damage by this pest is averted. Early research identified 3 problems with the practice of adult control, each of which has been addressed by the Areawide Management Program.

The 1st problem was that broad-spectrum insecticides were applied to control the beetles. These insecticides adversely affected the natural field ecology by killing nontarget organisms. Many beneficial insects in the treated fields were killed allowing secondary pests such as corn leaf aphids, spider mites, and corn earworm [*Helicoverpa zea* (Boddie)] to proliferate and cause damage to corn. The Areawide Management Program uses a highly selective bait insecticide (SD insecticide marketed by Microflo) that targets corn rootworm beetles. The formulation is comprised of a small amount of carbaryl insecticide (0.1 oz/A) and the feeding stimulant curcubitacin. Curcubitacin is a bitter substance that rootworm adults crave and other insects tend to avoid, thus minimizing the affect of the insecticide application on nontarget organisms. In addition, the number of fields that receive an insecticide application is minimized by monitoring beetle populations and by making applications only to fields that exceed the economic threshold. This approach avoids unnecessary application of insecticides to fields with pest densities below the economic threshold.

The 2nd problem identified by previous research was related to the size of the area treated for rootworm beetle control. Often a single field was treated and the area of that field was insufficient for effective management of the pest population. Rootworm beetles are mobile and capable of dispersing several miles from the field where they emerge. Individual fields that were treated often became reinfested by beetles from nearby fields. The Areawide Management Program monitors all the fields in 16mi^2 blocks of land and maintains the beetle density in each field below the economic threshold to reduce the potential for dispersal among the fields. It is suggested these blocks are sufficiently large to effectively manage rootworm population by adult control.

The 3rd problem identified by previous research was the short residual life of insecticide applications; multiple applications were required for effective control. Environmental conditions such as wash-off by rain or degradation by sunlight reduced the activity of the insecticide. Fields that received rain after the insecticide treatment often had a resurgence of rootworm beetles from additional emergence or emigration into the field. Thus, beetle populations increased and exceeded the economic threshold so that additional insecticide applications were required.

This paper reports the results of research directed at developing improved insecticide formulations that resist wash-off by rain.

Slam® Insecticide

Slam® is an insecticide formulation produced by Microflo for the control of corn rootworm adults. The insecticide is a coarse, dry product to be applied as a spray of large droplets. The current recommendation for aerial application is to mix Slam® with an adjuvant such as Windbrake to improve rainfastness. Recommendations suggest applications of Slam® at ⅜ lb/acre (at 13% a.i. = 0.05 lb a.i./A) in 1 gal of total spray.

There are currently 2 formulations of Slam® produced by MicroFlo. Prader has been used extensively but is expensive to manufacture. The other formulation is SD and it is cheaper to manufacture than Prader. The SD formulation was sold in 1994 for a short time but was withdrawn from the market, in part, due to its short residual activity.

Experimental Formulations

Four experimental formulations were tested in addition to the commercial formulations Prader and SD. Gluten, a product from wheat, and lignin, a product of the paper industry, were tested as additives to the SD formulation. These soluble powders were added in various amounts and were measured in relationship to the amount of water in the final spray. Therefore, a 1% gluten formulation contains ≈40 g (0.09 lb) of gluten per gallon of spray. These additives dissolve in the spray tank. As the spray droplets dry on the plant, the added ingredients essentially stick the insecticide to the plant. Once dry, these formulations resist wash-off by rain and residual activity of the insecticide is extended.

Small Plot Experiments

Experimental and commercial formulations were hand applied on 17 July 1998 to corn plants grown in small-field plots in Peoria, IL. Commercial formulations included Prader alone, SD alone, and SD with Windbrake. Experimental formulations included SD with 0.5% gluten and SD with 1.0% gluten. Once dry, treated leaf samples were collected and taken to the laboratory to represent the no-rain treatment for each formulation. Within 2 d of the insecticide application, a

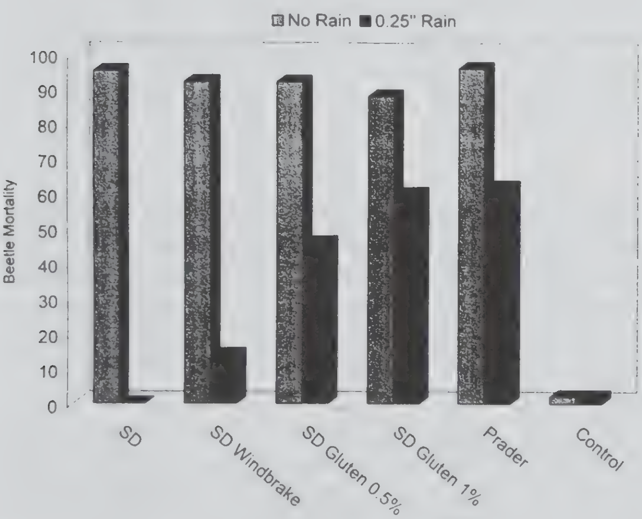

Figure 1 • Percentage of mortality of western corn rootworm beetles exposed to corn leaves treated with Slam® insecticide formulations and 0.25 in. of natural rain (spring 1998).

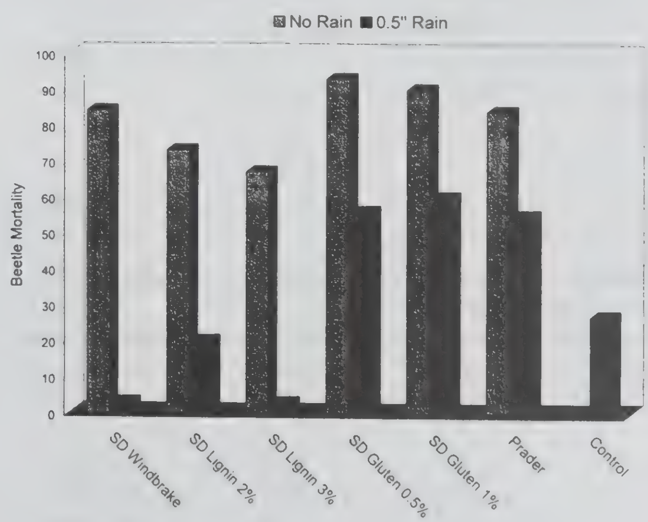

Figure 2 • Percentage of mortality of western corn rootworm beetles exposed to corn leaves treated with Slam® insecticide formulations and 0.5 in. of natural rain (fall 1998).

0.25-in rain fell on the plots and a 2nd leaf sample was collected for each insecticide formulation. Treated leaf sections were placed in petri dishes with 10 laboratory-reared western corn rootworm (*Diabrotica virgifera virgifera* LeConte) beetles. After 24 h, live and dead beetles were counted to indicate the amount insecticidal activity remaining for each treatment.

All of the insecticide treatments collected before the rain had good insecticidal activity and killed ≈90% of the beetles (Figure 1). After the rain, only leaf samples from the 2 SD with gluten formulations and the Prader formulation killed between 50 and 60% of the beetles. Leaves treated with SD alone or SD with Windbrake had little to no activity left (zero to 14% beetle mortality).

A 2nd laboratory experiment was done as formulations were applied to late-planted corn on 30 September 1998. In addition to the formulations described previously, experimental formulations in this test also included SD with 2% lignin and SD with 3% lignin. Plants in this experiment received 0.5 in. of rain the day after insecticide application. Leaf samples were collected and placed in petri dishes with western corn rootworm beetles to determine the amount of insecticidal activity remaining after rain. Also, an additional leaf sample was collected 7 d after application and an additional 0.9 in. of rain fell on the plots.

Results of this 2nd experiment were similar to the 1st small-plot experiment. The SD with Windbrake formulation was washed from the plants with the 0.5 in. of rain (Figure 2). The SD with gluten and Prader formulations resisted wash-off as indicated by beetle mortality. After the rain, these formulations killed ≈50% of the rootworm beetles. The SD formulations with lignin were not as effective as the formulations with gluten. There was no insecticidal activity remaining on leaf samples collected after 1.4 in. of rain.

Table 1 • SD treatments applied to field corn for control the adult corn rootworm, 1998.

Treatment #	Active	Formulation	Formulation rate
1	SD		
2	SD	Gluten	0.5% solids
3	SD	Gluten	1.0% solids
4	SD	Lignin	2.0% solids
5	SD	Lignin	3.0% solids
6	Prader	Windbrake	4 oz/30 gal
7	untreated	—	—

Table 2 • Rainfall (mm) recorded at each field included in the corn rootworm experiment, 1998.

Field #	County	11 August	18 August	25 August	28 August
1	Whiteside	6	10	19	36
2	Whiteside	6	10	26	38
3	Whiteside	10	8	24	36
4	Ogle	4	8	20	32

Field Experiment 1998

Three 80-acre fields in Whiteside County and 1 field in Ogle County were selected for this experiment. Six insecticide formulations were applied to 11-acre plots at each field, at a rate of 0.5 lb/A of Slam® on 6 August. Treatments were aerially applied with a Rockwell Thrush S2R at 115 mph through #6 orifice nozzles to provide an application rate of 1 gal/A. The spray pattern was sampled using water-sensitive cards placed about 4 ft apart for ≈60 ft perpendicular to the direction of application. The cards indicated a uniform application of relatively large droplets over a spray swath of ≈50 ft. Experimental formulations of SD included gluten (0.5 or 1%) and lignin (2 or 3%) (Table 1). Two commercial formulations were applied for comparison, SD and Prader with Windbrake. A control (no insecticide) treatment was included at each field.

Densities of corn rootworm beetles in each plot were determined using Pherocon AM sticky traps. When using these traps, the recommended economic threshold for insecticide application is ≥5 beetles per trap per day. In each plot, traps were arranged in 2 rows with 5 traps each. Trap rows were 40 rows apart, 20 rows from the center of the plot, and 50 rows from the nearest edge of the plot. The 1st trap in a row was placed on a corn

Table 3 • Average number of corn rootworm beetles caught each day in traps for 3 wk after Slam® applications, 1998.

Treatment #	Active	Formulation	Average[1] beetles/trap/day
1	SD		0.73b
2	SD	Gluten	0.62ab
3	SD	Gluten	0.46a
4	SD	Lignin	0.51a
5	SD	Lignin	0.90c
6	Prader	Windbrake	0.60ab
7	untreated	—	3.12d

[1] Means followed by the same letter are not significantly different, LSD, $P = 0.05$.

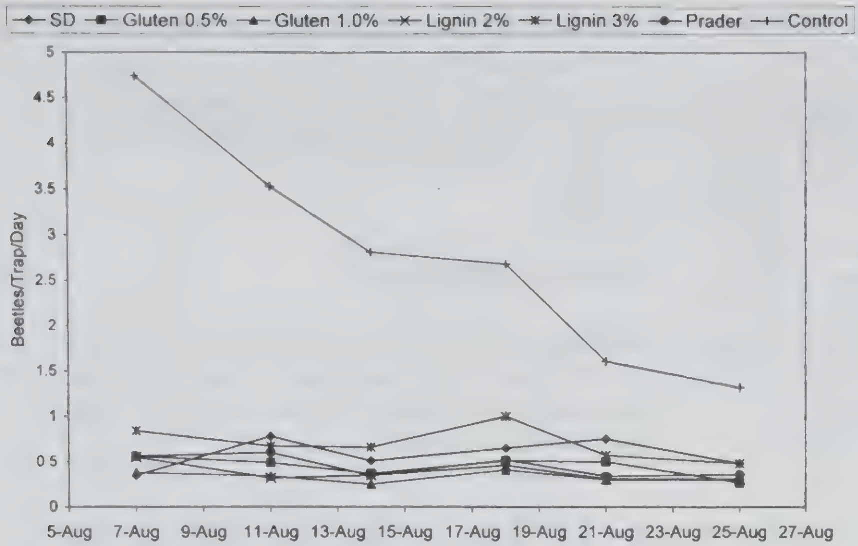

Figure 3 • Corn rootworm beetle densities in corn plots treated with different formulations of Slam® insecticide 1998.

plant ≈400 ft from the end of the field and traps in a row were separated ≈100 ft. Each trap was placed on a corn plant one leaf above the ear. Traps were placed in the fields 2 d prior to insecticide applications and removed before application to provide a preapplication evaluation of the beetle density for each plot. Traps were again placed in the field the day after application and exchanged twice per week for the following 3 wk. After traps were collected, corn rootworm beetles were counted to determine the number of beetles caught per day. Lady beetle and lacewing adults also were counted to represent the density of beneficial insects in each plot.

A rain gauge was located at each field to measure the amount of precipitation after application. Precipitation was recorded only when the traps were exchanged (Table 2).

Before the insecticide treatments were applied to cornfields, the traps in the untreated plots caught ≈8 beetles per trap per day, exceeding the economic threshold. Beetle densities were declining at this time as indicated by a general decline of trap catches from earlier evaluations. After insecticide applications, spray deposits were visible on the leaves in each of the treated plots. Live and dead beetles also were observed in each of the treated plots shortly after application. Also, beetles were observed feeding on spray deposits, indicating that experimental formulation did not inhibit feeding.

Field Experiment Results

Each of the insecticide treatments effectively controlled the corn rootworm adults (Figure 3). Trap counts indicated that densities of corn rootworm beetles were low for 3 wk following application in each of the plots receiving Slam® formulations. Formulations of SD with gluten and Prader provided slightly better beetle control than did the other treatments. The SD and SD with 3% lignin formulations tended to have slightly higher beetle densities than did the other insecticide-treated plots. The SD formulation alone may have been washed from the plants by the first rain (Table 2) and allowed some reinfestation by dispersing beetles. The SD with 3% lignin formulation had mixing and application problems that may have adversely affected control. None of the plots had beetle densities that approached

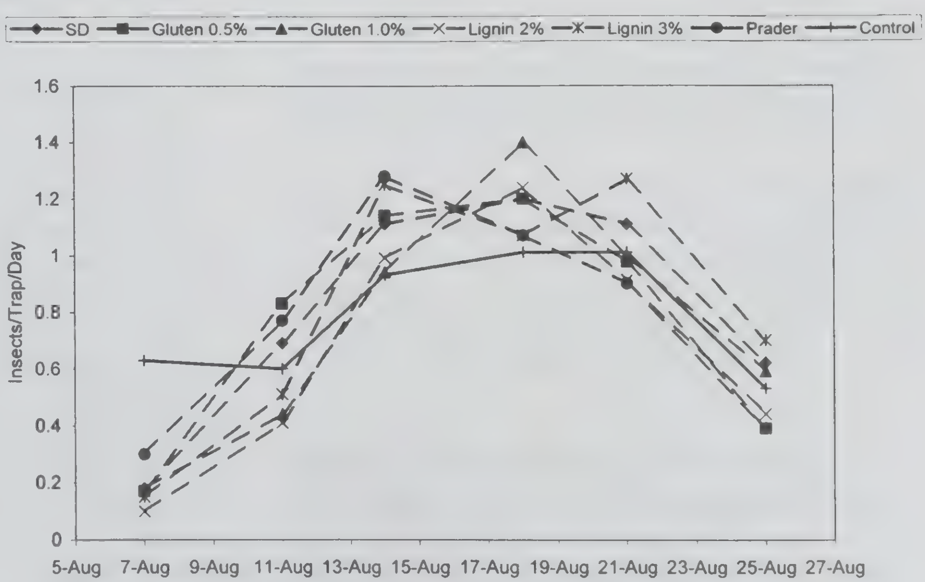

Figure 4 • Densities of beneficial insects (lady beetles and lacewings) in corn plots treated with different formulations of Slam® insecticide 1998.

the economic threshold for the 3 wk after application; however, when all samples after application were combined, the beetle densities were significantly higher in plots treated with the SD and SD with 3% lignin formulations (Table 3) than in the other plots receiving Slam® formulations.

Beetle densities in the untreated plots steadily declined for this 3-wk period. Traps in untreated plots averaged ≈8 beetles per trap per day prior to application and 5 beetles per trap per day immediately after application. The number of beetles caught in untreated plots declined to <2 beetles per trap per day after 3 wk.

Summary

Of the 2 commercial formulations of Slam®, Prader had longer residual activity than SD; however, when gluten was added to SD, residual activity was improved and was comparable to that of Prader. Because of the economics associated with the SD process, Microflo is currently evaluating this technology for marketing purposes in the near future.

Acknowledgement

We gratefully acknowledge the contributions of Tim Jakobs, David Jakobs, and Norbert Jakobs for allowing us to use their fields in Whiteside and Ogle counties for the field experiments.

This article reports the results of research only. Mention of a proprietary product does not constitute an endorsement or a recommendation by the USDA for its use.

SPRAYING SOYBEANS FOR ROOTWORM MANAGEMENT: OUR STANCE

Kevin Steffey and Mike Gray

Since 1986, we have stated in our insect management recommendations that spraying insecticides to kill corn rootworm adults (*Diabrotica* spp.) before females deposit eggs *in corn* (*Zea mays* L.) as a viable alternative for rootworm management. In the *1996 Illinois Pest Control Handbook*, we articulated an important requirement and a warning. The requirement was as follows: "A rootworm beetle suppression program should be employed only if the fields are under the supervision of trained pest management personnel in weekly scouting programs. Careful field scouting is a requirement." The warning was as follows: "Ideally, one properly timed spray should *replace* a soil insecticide. Unfortunately, some fields will require two sprays to combat extended beetle emergence and egg laying. Two sprays or a spray plus a soil insecticide the following season may hasten the onset of rootworm resistance to insecticides." The requirement and the warning persist in our current recommendations. To address the burgeoning problem with western corn rootworm (*Diabotrica virgifera virgifera* LeConte) females laying eggs in soybeans [*Glycine max* (L.) Merrill] in east central Illinois, we added another statement to our recommendations in the *1997 Illinois Agricultural Pest Management Handbook*: "An adult management approach to prevent egg laying by western corn rootworms in soybeans currently is not recommended. Until sampling strategies and economic thresholds can be developed, growers are encouraged not to attempt this strategy to prevent corn rootworm larval injury in corn planted after soybeans." This statement was compelled by our learning that some people were recommending this practice in 1996 and that some soybean fields were sprayed to prevent western corn rootworm females from laying eggs. We first expressed our concern in issue number 20 (9 August 1996) of the *Pest Management & Crop Development Bulletin*. We expressed our concern in the *Bulletin* again in 1997 (issue number 18, 25 July 1997) and in 1998 (issue number 17, 17 July 1998). Despite our clearly stated criticism of this approach, some people persisted in recommending control of western corn rootworm adults to prevent egg laying in soybeans, culminating in our strongly worded article, "Two Strikes and You're Out?" in issue number 19 (July 31 1998) of the *Bulletin*.

The failures of some soil insecticides to provide adequate root protection in several fields in Illinois in 1997 and the intensity of western corn rootworm damage in some fields of corn planted after soybeans in east central Illinois have generated significant concern among corn growers. Consequently, they are examining other potential rootworm management strategies. Although we understand that some growers and dealers are frustrated with the rootworm problems, we cannot support a management strategy that has little if any scientific foundation.

A discussion about the history, benefits, and limitations of the strategy of spraying rootworm adults to prevent egg laying is in order. Some of this discussion was extracted from Steffey and Gray (1993). We conclude this paper with a reiteration of our stance regarding the application of this strategy in soybeans.

History of Adult Corn Rootworm Management as an Alternative to Soil Insecticides

The practice of killing rootworm adults to prevent females from laying eggs has been tested and used since

the late 1960s. The first scientific report of this practice was Pruess et al. (1974). They tested the feasibility of applying ultra-low volumes of malathion to reduce egg laying by rootworm adults in a 16 mi^2 area in Nebraska in 1968, 1969, and 1970. They were able to reduce densities of western corn rootworms in subsequent seasons by 39, 54, and 72%, respectively. In their paper, they concluded, "The program was successful to the extent that no economic infestations occurred in the treated area during any year following adult control while use of soil insecticides was virtually abandoned in that area. But this achievement was accomplished only by a greater total use of insecticide, applied to the total environment, without cumulative benefits."

The success of the experiment elucidated by Pruess et al. (1974) fostered an increased interest in managing rootworm adults, rather than controlling the larvae. Union Carbide was the first company to investigate the use of one of their products, Sevin 4 Oil (active ingredient carbaryl), for controlling corn rootworm adults to prevent females from laying eggs. The approach promoted by Union Carbide was based upon controlling adults in individual fields, rather than controlling adults over a large area. Investigations by Union Carbide researchers began in 1973 at a time when some of the soil insecticides were not performing as well as expected. The initial testing of the adult corn rootworm management concept predates the appearance of some of our modern soil insecticides (e.g., Counter, Force, Lorsban) on the market. The history of the research with Sevin 4 Oil and the educational conferences conducted to discuss the research has been documented by Union Carbide (1977—1979).

By the late 1970s, Union Carbide was actively promoting the use of Sevin 4 Oil to prevent corn rootworm females from laying eggs, thereby eliminating the need for a soil insecticide to protect corn roots in corn planted after corn. One of their objectives was to teach responsible dealers and their personnel the proper scouting, identification, and evaluation techniques that were unique to the adult corn rootworm management program.

Many growers, pesticide dealers, and aerial applicators were excited about this alternative for rootworm management. At least one private consultant in Nebraska and one in Iowa were recommending the program with the provision that it should be implemented properly by trained scouts. In 1979, an estimated 12,000 acres of corn in Illinois and Indiana were involved in this program. Approximately 13,000 acres of corn were involved in the program in Iowa.

By 1979, extension entomologists in the Corn Belt were suggesting that the adult corn rootworm management program was a possible alternative to soil insecticides for corn rootworm management. All states' recommendations, however, were explicit about the guidelines for implementing the program precisely:

- For cornfields enrolled in an adult corn rootworm management program, begin scouting by the 1st week in July, and scout weekly through the end of August. Examine at least 10 plants in each of 5 locations per 40 acres.
- Examine either the entire plant or the ear zone for rootworm beetles. The ear zone is defined as the zone that includes the top surface of the leaf below the ear node, both surfaces of the leaf at the ear node, the ear and its silks, and the bottom surface of the leaf above the ear node.
- Determine the percentage of the female population of corn rootworms that is gravid (with eggs). To do this, one must be able to differentiate between male and female beetles and then determine whether the females are gravid. Although male and female western corn rootworms can usually be differentiated by their external appearance, the sex of the northern corn rootworm (*Diabrotica* barberi Smith & Lawrence) is more difficult to determine. One method of differentiating the sexes of both corn rootworm species is to squeeze the abdomen of a beetle gently to expose the sex organs. The male organ (aedeagus) extends and curves downward. The female organ (ovipositor) extends outward and curls.

  To determine if a female is gravid, hold her between your thumb and forefinger and squeeze the abdomen. If a pure white, milky substance is squeezed out, the female is not gravid. If the substance contains cream-colored eggs, she is gravid. A gravid female usually has a swollen abdomen.
- If rootworm beetle densities reach or exceed 1 beetle per plant or 0.6 beetle per ear zone and 10% of the females is gravid, application of Sevin 4 Oil to prevent rootworm females from laying eggs is warranted. Proper timing is critical. Do not treat fields unless they have been scouted from the 1st wk of July. Do not treat fields that have had 1 or more beetles per plant with 10% of the females gravid for >7 d. It is too late for an adult control spray to reduce egg laying to subeconomic levels in these fields. Instead, use a soil insecticide next spring.

- Continue to scout fields after treatment and through the end of August to determine whether beetle numbers build up. If beetle populations reach or exceed 0.5 beetle per plant or 0.3 beetle per ear zone in a treated field, a 2nd application of Sevin 4 Oil is necessary.

Throughout the 1980s, the practice of controlling corn rootworm adults to prevent females from laying eggs caught on significantly only in some areas of Nebraska and Iowa where experienced private consultants were able to ensure the success of the program. The product recommended by consultants, however, for management of adult corn rootworms in most areas of the Corn Belt changed from Sevin 4 Oil to Penncap-M (active ingredient methyl parathion). The success of Penncap-M in adult corn rootworm management programs, especially in Nebraska, was touted by many consultants and representatives of Pennwalt, the company that manufactured a sold Penncap-M. Eventually representatives of Elf Atochem, the company that now sells Penncap-M, became more aggressive in marketing Penncap-M for management of adult corn rootworms. As a consequence, the use of Penncap-M in rootworm beetle suppression programs has gained a foothold in some areas of the Corn Belt, including northern Illinois.

Benefits and Limitations of Adult Corn Rootworm Management as an Alternative to Soil Insecticides

Despite documented evidence that many acres of corn treated with soil insecticides are treated unnecessarily (Turpin and Thieme 1978, Gray et al. 1993), most growers continue to apply soil insecticides for rootworm control as preventive "insurance" treatments to corn planted after corn. A program of controlling rootworm adults to prevent females from laying eggs must be based on scouting, thresholds, and insect biology, so adult corn rootworm management programs, if conducted properly, accommodate the pest management concept of treating only when necessary. In addition, an adult corn rootworm management program is cost-comparable with and occasionally cheaper than application of soil insecticides, as long as only 1 application of the aerially applied insecticide is required. Finally, the insecticide used in an adult corn rootworm management program is handled by experienced applicators, whereas soil insecticides are applied by the growers. As a consequence, growers could use the adult corn rootworm management program and relinquish concern about handling insecticides.

The limitations of the adult corn rootworm management program in corn include the complexity of implementing the program successfully, the potential repercussions of making broadcast applications of insecticides, and the potential lack of sufficient infrastructure (enough aerial applicators, consultants, and scouts) to treat a lot of corn acres in a given year. The first 2 limitations deserve further comment.

An adult corn rootworm management program will work only if experienced or well-trained individuals committed to scouting and IPM conduct the program. The prerequisites for a successful adult corn rootworm management program are complex. One must be able to identify both species (western and northern), distinguish between the sexes, and determine whether the females are gravid. Frequent scouting trips and precise scouting techniques are also requirements. Failure to implement the adult corn rootworm management program precisely can result in poor control of rootworm larvae the following year, with obvious economic consequences.

Regarding broadcast applications of insecticides for rootworm control, potential repercussions include detrimental effects to beneficial insects (predators, parasitoids, and pollinators) and development of rootworms resistant to insecticides. The former concern possibly could be alleviated if a more benign product (e.g., Slam®) were used in an adult corn rootworm management program. Slam®, manufactured by MicroFlo Company, is comprised of carbaryl (13%), *Cucurbita foetidissima* H.B.K. (bitter squash) root powder (65%), and unidentified carriers (22%). The bitter squash powder is an arrestant and feeding stimulant for rootworm adults, which feed compulsively after they encounter the powder. While eating the product after it is applied, the adult rootworms ingest lethal doses of carbaryl. Slam® does not seem to harm beneficial insects because the bitter squash powder is distasteful to them and the amount of carbaryl applied per acre is small, <1 oz. Slam® currently is the product of choice in the areawide management program being conducted jointly by entomologists with the University of Illinois, Purdue University, and the United States Department of Agriculture (Buhler et al. 1998).

The other major concern associated with broadcast applications of insecticides for rootworm control—that is, rootworms becoming resistant to the insecticides used—is a reality. The 1st report of rootworm resistance to the cyclodiene insecticides came from Nebraska where western corn rootworms became resistant to aldrin (Ball and Weekman 1963). The cyclodiene-resistant strain of the western corn rootworm spread

from a single locus in southeastern Nebraska until by 1980 it encompassed almost the entire Corn Belt (Metcalf 1980). More recently, resistance of western corn rootworms to a couple of adulticides has been documented. Meinke et al. (1998) confirmed that western corn rootworms have developed resistance to methyl parathion (active ingredient of Penncap-M) and carbaryl (active ingredient of Sevin) in areas of Nebraska where broadcast applications of these products have been common for years. The F1 generation also displayed resistance characteristics, confirming the heritability of this trait. Meinke et al. (1998) determined that larval progeny from methyl parathion-resistant adults are more tolerant than progeny from susceptible adults to the active ingredients in selected soil insecticides. The intensity of the relationship, however, varies among compounds in different insecticide classes. The potential implications of this preliminary finding are sobering considering the dispersal capabilities of western corn rootworms and corn producers' heavy reliance on soil insecticides.

Spraying Soybeans for Rootworm Management: Our Stance

An outline of our concerns about spraying soybeans for rootworm management should reiterate our stance:

- There is no threshold for treating western corn rootworm adults in soybeans. The threshold we have developed based upon captures of rootworm adults on yellow Pherocon AM sticky traps was designed to assist growers in making decisions regarding the use of a soil insecticide the following spring. The "Two Strike Program" promoted by some FMC representatives, involves misuse of our thresholds to trigger application of Furadan 4F to control rootworm adults.
- Timing of insecticide sprays to control rootworm adults in soybeans is not known. Much research remains to be conducted before we can determine when peak egg laying occurs in soybean fields. Treating soybean fields with insecticides too early or too late may result in unsatisfactory root protection the following year.
- The threat of western corn rootworms developing resistance to insecticides should be enough to deter widespread broadcast applications of insecticides to kill the adults. Western corn rootworms are resistant to methyl parathion and carbaryl in some areas of Nebraska (Meinke et al. 1998), and the potential for their spread to the east or for independent development of resistance in Illinois exists. Application of an insecticide one year to control adults followed by application of a soil insecticide the next year to control larvae makes even less sense. Treating two life-cycle stages of an insect is one of the quickest ways to expedite the development of resistance to insecticides (Metcalf 1994).

The approach of treating soybean fields to prevent rootworm females from laying eggs has merit. In the future, if we are able to determine appropriate thresholds and timing application of from our research, we should be able to recommend adult corn rootworm management in soybeans. For the time being, our stance about spraying soybeans for rootworm management is simple: don't do it.

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TRANSGENIC INSECTICIDAL CULTIVARS FOR CORN ROOTWORMS: RESISTANCE MANAGEMENT CONSIDERATIONS

Michael E. Gray

Monsanto says its corn resists the rootworm." This was the headline of an article in the *Wall Street Journal* on August 21, 1998. The article provided the following information: "Monsanto said yesterday that it has conducted multiple field trials in the Midwest of corn equipped with several genes that make proteins deadly to rootworm. A company spokesman said at least one of the genes comes from a plant that isn't corn, and that others come from soil microorganisms. Monsanto didn't give more details." Depending on the speed of the regulatory process, Monsanto announced that they intend to commercialize this revolutionary transgenic seed within the United States by 2001 or 2002. Other companies also are in the race to market transgenic insecticidal cultivars for corn rootworms (*Diabrotica* spp). Mycogen Corporation and Pioneer Hi-Bred International Incorporated are cooperating in an effort to produce transgenic corn rootworm hybrids. Novartis AG also has announced the field testing of "rootworm-resistant corn." If these scientific and commercial efforts are successful, American corn producers will have a new tool at their disposal that can be aimed at one of the most destructive insect pests of corn, the corn rootworm complex. The purpose of this paper is to review some key elements of rootworm biology and behavior and to provide insight on how this knowledge may prove useful in the development of resistance management plans for this exciting new technology. ***Because we know virtually nothing about potential resistance mechanisms for corn rootworms and transgenic hybrids, including the underlying genetic basis for potential resistance development, much of the following discussion regarding resistance is speculative.***

The use of transgenic cultivars for pest management represents a revolutionary change for modern agriculture. The changes will be as profound as the introduction of broad spectrum pesticides following World War II and the adoption of corn hybrids by farmers. The potential agronomic and economic benefits of using transgenic insecticidal cultivars for the management of corn rootworms are impressive. Indeed, Metcalf (1986) described corn rootworms as the billion dollar insect complex. The $1 billion dollar estimate is based upon costs associated with the purchase of soil insecticides and the crop losses due to corn rootworm damage. Because the use of transgenic insecticidal cultivars for the management of insect pests is relatively new, we have few examples of how producers are likely to respond to this revolutionary technology. We are fortunate, however, to have the results of Pilcher and Rice (1998) to draw upon regarding the perceptions of Iowa farmers to *Bacillus thuringiensis* (*Bt*) corn for European corn borer [*Ostrinia nubilalis* (Hübner)] and corn rootworm management. In all, 799 of 3,000 producers (26.6%) responded to their questionnaire. Based upon the results of the survey, 29.5% of the farmers were *enthusiastic* and 43.6% were *cautiously optimistic* about prospects for a transgenic hybrid that could control corn rootworm larvae. Overall, producers were even more enthusiastic about controlling corn rootworms than European corn borers with a transgenic cultivar. Regarding the potential advantages of transgenic cultivars for corn rootworm control, Pilcher and Rice (1998) summarized the following producers' perceptions: "Of 775 responses, 40.5% of the farmers felt that less insecticide in the environment would be the greatest advantage, whereas 21.2% thought that less insecticide exposure to farm workers was very important. The combined response of these two categories emphasizes the importance of reduced insecticide use to farmers. Yields would be the most important advantage to many farmers (20.4%). Also, 10.6% said *B.*

thuringiensis being specific to corn rootworm would be the greatest advantage." Producers also were asked to identify the greatest disadvantage to the use of transgenic cultivars for corn rootworm control; Pilcher and Rice (1998) summarized the farmers' responses: "Of 766 responses, 34.6% of the farmers felt that development of resistance was the greatest disadvantage, followed by *B. thuringiensis* corn being specific against corn rootworm (31.2%). Farmers also perceived harm to soil microorganisms (16.1%) and lower yields (13.8%) as being important. Managing soil insects is difficult, but farmers often apply a soil insecticide as a protective measure whether it is needed or not (Turpin 1977). Using *B. thuringiensis* corn would allow management of corn rootworm to be much simpler, but resistance management and the lack of broader insect control could pose some problems." How quickly will producers adopt transgenic cultivars for corn rootworm control? Pilcher and Rice (1998) found that farmers, described as innovators (23.4%), were those most likely to use transgenic hybrids for European corn borer control soon after the cultivars became commercially available. Approximately half (48%) of the producers surveyed indicated that they would probably wait a year or two before growing a transgenic cultivar for European corn borer management.

Adoption of transgenic hybrids for corn rootworm control is expected to be much swifter. Most farmers, particularly those who produce continuous corn, annually use soil insecticides for corn rootworms as a regular part of their corn production system. Most producers view the use of insecticides for European corn borer management from a different vantage point. Of the producers surveyed by Pilcher and Rice (1998), nearly one-third (32%) did not manage European corn borers, instead, they simply *ignored* them. Many farmers (43.6%) responded that they limit losses caused by European corn borers primarily through early harvest of their fields. Historically, because most producers have not allocated resources for the management of European corn borers, the purchase of a transgenic hybrid represents a new input cost in the production of a given crop. The scenario for corn rootworm management could not be more different. Ultimately, producers are much more likely to trade the costs associated with the use of a soil insecticide for that of a transgenic cultivar to manage corn rootworms. Assuming the costs will be comparable.

Perhaps the chief concern raised by scientists regarding the commercialization of transgenic insecticidal cultivars for corn rootworms is the potential development of resistance. Western corn rootworm (*Diabrotica virgifera virgifera* LeConte) has demonstrated a strong proclivity to develop resistance to insecticides, and perhaps even more spectacularly, to crop rotation in east central Illinois and Indiana. The development in east central Nebraska and spread throughout the Corn Belt of a resistant western corn rootworm strain to the chlorinated hydrocarbon soil insecticides, is by now, a familiar example for students of pest management regarding how rapidly insecticide resistance can occur (Gray and Luckmann 1994). Aldrin was used in Nebraska from 1952 to1961 to limit losses caused by western corn rootworm. The LD_{50} value obtained from 19 collection sites in Nebraska was 1539 mu-g/g in 1962. Nearly 20 years later (1981), the LD_{50} value was approximately fourfold less at 355 mu-g/g (Ball 1983). The resistant western corn rootworm strain spread rapidly, and by 1980, corn production across much of the Corn Belt was affected (Metcalf 1986).

Adult corn rootworm management practices have been recommended by the consultant industry in Nebraska for decades and popularly subscribed to by many producers as an alternative to soil insecticides. Unfortunately, the broadcast adulticides were in most cases the sole management tactic used by many growers. Meinke et al. (1998) confirmed that western corn rootworms have developed resistance to methyl parathion (16.4 fold) and carbaryl (9.4 fold) in areas of Nebraska where applications of these products have been common for years. The F_1 generation displayed resistance characteristics confirming the heritability of this trait. Meinke et al. (1998) also determined "that larval progeny from methyl parathion-resistant adults are more tolerant than progeny from susceptible adults to the active ingredients in selected soil insecticides, but the intensity of this relationship varies across compounds within and among insecticide classes (L.J.M. and B.D.S., unpublished data)." The potential implications of this preliminary finding are sobering considering the dispersal capabilities of this insect and the heavy reliance upon soil insecticides by most producers across the Corn Belt and in eastern states affected by this pest. ***Due to the failure of crop rotation as a viable corn rootworm management option in the eastern Corn Belt, the spread of an organophosphate resistant strain of western corn rootworm would pose a significant corn production challenge to producers.*** Understandably, producers are increasingly eager for the commercialization of transgenic hybrids for corn rootworms.

Dispersal Characteristics of Western Corn Rootworm Larvae and Adults

The dispersal characteristics of western corn rootworms are impressive. Hill and Mayo (1980) reported that from 1950 to 1980, the western corn rootworm "largely" displaced the northern corn rootworm (*Diabrotica barberi* Smith and Lawrence) as the dominant species in eastern Nebraska. Western corn rootworm is a superior competitor to northern corn rootworm and eventually displaces it as the dominant rootworm species where ranges of the two overlap (Piedrahita et al. 1985; Gray and Tollefson 1987, 1988; Woodson 1994). Throughout the 1960s and 1970s, the western corn rootworm migrated eastward across the Corn Belt. The western corn rootworm was officially recorded in southwestern Michigan in 1971 (Ruppel 1975). Dispersal throughout the state was estimated at 50 miles to the north, 38 miles to the northeast, and 25 miles eastward on an annual basis. By 1974, western corn rootworm had infested all major corn growing regions in Michigan. By the mid 1980s, western corn rootworm beetles could be found in cornfields of southwest Virginia (Youngman and Day 1993). From 1987 to 1992, surveys indicated a rapid dispersal through continuous corn regions of Virginia, movement was less rapid into areas of the state where crop rotation was practiced more often.

Larval Movement

The movement of corn rootworm larvae through the soil profile has been thoroughly characterized. Suttle et al. (1967) and Short and Luedtke (1970) conducted studies that showed even when corn rows were separated by row widths of 40 inches, larvae could inflict injury. In essence, eggs hatching between rows still had reasonable prospects for survival. Short and Luedtke (1970) determined that western corn rootworm larvae were capable of moving distances in the soil up to 12 and 16 inches in 1967 and 1968, respectively, in Nebraska field experiments. Progressively fewer larvae were able to move beyond distances of 12 inches. Short and Luedtke (1970) concluded that western corn rootworm larvae should be able to infest corn roots regardless of row spacing used in commercial cornfields.

How corn rootworm larvae locate roots has been the subject of much research and speculation. Strnad et al. (1986) proved that western corn rootworm larvae were able to detect CO_2 gradients and hypothesized that larvae may use this ability to locate respiring corn roots. In a follow-up experiment, Strnad and Bergman (1987a) investigated the horizontal and vertical movement of first instars of western corn rootworm within chambers that contained silt, loam, sandy loam, or sand at different bulk densities. In uncompacted soils, larvae were evenly distributed within 6 hours in the absence of a CO_2 source. When CO_2 was introduced in one end of the soil chamber, more than 66% of the larvae moved at least 25 cm towards the source. As soil bulk densities increased, larval movement was impeded. Strnad and Bergman (1987b) reported the preference of western corn rootworm first, second, and third instars for actively growing root tissue. Orientation of larvae was more pronounced towards rather than away from root tips. Larvae tended to concentrate in distal areas of roots. During the later portions of the larval feeding period, larvae abandon older roots and move through the soil profile and begin feeding on newer and shorter roots. As third instars begin to concentrate around the bases of plants, newly formed brace roots are severely injured promoting lodging and subsequent yield losses. Strnad and Dunn (1990) characterized the host searching behavior of neonate western corn rootworm larvae as *ranging* (straight form of locomotion) and/or *localized* (more convoluted locomotion). Larvae were found to shift from more long distance ranging locomotion to localized searching after 5 minutes of contact with root tissue of corn and wheat. Contact with oats, giant foxtail, or soybean roots did not cause a shift away from ranging motion. Strnad and Dunn (1990) reported that larvae were not attracted to CO_2 after contact with corn roots had been achieved. Larvae that were unable to contact corn roots and also were not exposed to CO_2 moved the furthest in the experiments (98.4 mm). Bernklau and Bjostad (1998) recently verified the importance of CO_2 in attracting western corn rootworm larvae to corn roots: ". . . CO_2 is the only volatile compound that attracts western corn rootworm larvae to corn roots, (E.J.B., unplublished data), and that other volatile compounds from corn roots play no role in attraction." Bernklau and Bjostad (1998) further suggested that CO_2 (microbial and/or chemical sources) may be used in new pest management tools as orientation disruptors for western corn rootworm larvae as they seek out host tissue.

The detrimental effects of compaction and soil moisture on larval movement has been confirmed by several studies. Gustin and Schumacher (1989) observed that the movement of first-instars of western corn rootworm was restricted to less than 5 cm in soils with a bulk density of 1.1 mg/m^3; movement also was dependent upon the continuity of pores within the soil profile.

MacDonald and Ellis (1990) found that western corn rootworm larvae were most mobile when loamy soil was maintained at 24 and 30% moisture levels - average distances moved were 17.2 and 14.7 cm, respectively. In very wet soils (36%), larvae were far less mobile with average movement through the soil of only 2.7 cm. Movement through the soil profile was restricted in dry soils (18% moisture or less) as well. Movement of larvae also was significantly affected by soil type. Larvae moved on average only 6.1 cm in a loamy sand soil; however, in silty clay or loamy soils the distances covered were three times as great.

Corn rootworm larvae that hatch from eggs located between a transgenic corn row and a nontransgenic row of corn plants may feed on both root systems. If a larva (RS heterozygous larvae may be less susceptible; resistance trait may only be partially recessive) consumes less than a lethal dose of toxin from the transgenic plant, it is possible that feeding and ultimately continued development could occur on the adjacent nontransgenic root system. This may hasten the onset of resistance development (especially if resistance is partially recessive). Gould (1998) underscored the importance of understanding the mobility of larvae by offering a general summary statement relative to transgenic insecticidal crop sustainability: "Population genetic models indicate that unless transgenic insecticidal cultivars produce very high doses of toxin(s) relative to the target pest's LD_{99}, and are planted in a manner that allows high levels of mating among pest genotypes, while not permitting movement of feeding stages between toxic and non-toxic plants, effective refuge size needs to be much larger than the current standard of 4%." Knowledge of corn rootworm larval movement suggests that the use of large blocks of refuges (nontransgenic cultivars) is preferable to refuges planted in narrow strips from a resistance management perspective. A thorough understanding of the dynamics of corn rootworm larval movement and survival is crucial in deploying effective resistance management strategies.

Adult Movement

Northern and western corn rootworm adults are very mobile; in particular, the rate at which the western corn rootworm expanded its range, serves as convincing evidence of the strong dispersal capabilities of this species. Witkowski et al. (1975) observed that western corn rootworm flight behavior is bimodal with peaks taking place in 2 to 3 hour time periods after sunrise and prior to sunset. Flight behavior was reduced when the temperature was below 15° C and peaked within a range of 22.2 to 27.0° C. Van Woerkom et al. (1983) conducted experiments to determine the vertical distribution of western and northern corn rootworm beetles up to a height of 7.62 m. Results from the field investigations and wind tunnel experiments indicated the following: 1) low flight patterns, 2) beetle movement is strongly affected by wind, 3) males and females fly at different heights (female captures are nearly four times greater than males above crop canopy), 4) flight initiation decreases as wind speed increases, and 5) beetles are unable to direct their flight activity after wind speeds exceed 1.5 m/second. The likelihood of western corn rootworm adult movement into adjacent fields is a certainty. Western corn rootworm adults are typically passive fliers within the wind if prevailing currents exceed their potential flight speed. This behavior leads to low-level flight characteristics. Naranjo (1991) suggested that northern corn rootworm females leave cornfields as silks and pollen become increasingly scarce and return to these fields only for egg-laying purposes. Both species of rootworms emigrated readily from early-planted fields, whereas most western and northern corn rootworm adults were immigrants in late-planted fields.

Some investigators have explored the long-range migratory flight abilities of western corn rootworm adults. Coats et al. (1986) used western corn rootworm mated females (2 to 15 days posteclosion) that were field collected and flown on computerized flight mills. Flights were characterized as trivial (lasting typically less than 1 minute) or sustained (from 45 minutes to nearly 4 hours). Sustained flights were only made by females ranging from 2 to 9 days beyond eclosion. The greatest distance for a given flight was 24 km. During one 24-hour period, a beetle covered a distance of 39.6 km. Sustained flights occurred in the early morning and evening hours. Trivial flights were less regular and likely to occur throughout the day. Coats et al. (1986) summarized the western corn rootworm's impressive potential for migratory flight behavior as follows: "Projecting the mean distance covered per day (35 km) for sustained fliers over only the first 6 days of their life suggests that beetles are capable of unassisted flights covering well over 200 km."

Field observations by some researchers seem to support laboratory studies that indicate western corn rootworm adults are capable of long range flights. Grant and Seevers (1989) observed on numerous occasions (16) impressive numbers of western corn rootworm adults (primarily female) along the southern shoreline of Lake

Michigan during July through September (1984-1986). The presence of beetles along the shoreline appeared to coincide with the passage of cold fronts. Grant and Seevers (1989) speculated that as cold fronts moved through northern Indiana, beetles were deposited along the lakeshore, and they used this observation to suggest that western corn rootworm is capable of long-distance wind-assisted movement.

Corn rootworm adults consume several types of tissue on corn plants including the epidermis of corn leaves, pollen, tassels, and silks. If transgenic insecticidal cultivars are deployed for corn rootworms and they express toxic proteins in all plant tissues for the duration of a growing season, it is a certainty that two life stages of this insect will be exposed to pesticidal proteins before a single crop is harvested due to the mobility of adult corn rootworms. Rootworm adults will fly readily between even large and isolated blocks of transgenic and nontransgenic fields of corn. Modelers and those who are responsible for the development of resistance management plans must carefully consider the potential drawbacks of creating transgenic cultivars that express insecticidal proteins in all plant tissues throughout a growing season; thereby, exposing both life stages of corn rootworms to this novel technology.

Host Plant Range for Northern and Western Corn Rootworm

Clearly defining the host range of western and northern corn rootworm was an area of fertile research in the 1960s and early 1970s. Branson and Ortman (1967b, 1971) indicated that northern corn rootworm could complete its development on 14 species of graminaceous plants besides corn. In their experiments, adult northern corn rootworms that were reared on five noncorn hosts produced viable eggs. Branson and Ortman (1967c) also obtained viable western corn rootworm eggs from adults that had been reared as larvae on green and yellow foxtail (*Setaria* spp.). In other studies, Branson and Ortman (1967a, 1970) observed that western corn rootworm larvae survived 10 days on 18 graminaceous species, and completed immature stages on 13 species. Future research efforts (Branson 1971) revealed that western corn rootworm larvae could survive on 21 graminaceous species (not including corn); however, adults reared from some graminaceous species were significantly smaller than those reared on corn suggesting slight deleterious effects. In Branson's and Ortman's experiments (1967a, 1970), western corn rootworm larvae did not survive on 27 species of broadleaves (12 species of broadleaf weeds, 15 species of broadleaf crops). Branson and Ortman (1970) indicated that oats, sorghum, sudangrass, soybeans, flax, alfalfa, clovers, and sunflowers were not larval hosts and could be safely planted into fields that contained western corn rootworm eggs.

Although most research seemed to suggest that foxtail infestations might enhance corn rootworm survival, Johnson et al. (1984) reported that the presence of foxtails was a detriment to larval survival and adult emergence. Densities of larvae were reduced 7, 28, and 19% in plots infested with foxtail in 1981, 1982, and 1983, respectively. Fewer adults emerged from plots infested with foxtail; reductions in beetle emergence were 71, 32, and 72% in 1981, 1982, and 1983, respectively. Johnson et al. (1984) suggested that the presence of a large foxtail infestation may have resulted in smaller maize root systems; thus, decreasing the availability of a preferable larval food source. Although corn rootworm larvae are able to survive on the root systems of some *Setaria* spp., growth and development are less than optimal on these non-maize hosts.

Because western corn rootworms can complete their development on many species of weeds, most notably grasses (green and yellow foxtails, *Setaria* spp.) found commonly in cornfields, larvae may be able to ingest less than a lethal dose of a toxic protein present within a transgenic plant, stop feeding, move to an adjacent foxtail root, and then resume feeding and development. This scenario has potentially important implications regarding the development of appropriate resistance management strategies. If heterozygous larvae (RS) for the resistance trait are less susceptible (the resistance allele is only partially recessive) to an insecticidal protein, then resistance development might be hastened due to larval movement between roots of transgenic rootworm cultivars and grassy weeds. ***Additionally, if susceptibility differences exist among corn rootworm larval instars to transgenic insecticidal proteins, first instar larvae may begin feeding on the roots of Setaria spp.; however, they might eventually complete their development unscathed as more mature and less susceptible larvae on transgenic roots.***

Use of Soil Insecticides and Transgenic Insecticidal Cultivars for Corn Rootworms

The investment by American producers in soil insecticides to stem the losses caused by corn rootworms has few, if any, parallels in the chronicles of pest management. To date, crop rotation and the prophylactic use of soil insecticides represent the main approaches by which farmers cope with the corn rootworm complex. In the

early 1970s, producers began to use organophosphate and carbamate soil insecticides after the chlorinated hydrocarbon products were banned from use.

Sutter et al. (1991) maintained that because soil insecticides did not reduce survivorship enough to prevent future infestations of western corn rootworm, they represented a poor long-term pest management solution. The results of Gray et al. (1992) supported this contention. In their three-year study (1983-1985) conducted in Illinois, greater western corn rootworm emergence occurred in insecticide-treated (carbofuran, chlorpyrifos, and terbufos) compared with untreated areas in some years, indicating that soil insecticides are not good population management tools (general equilibrium position of population is maintained). Soil insecticides applied in narrow bands (7-inch or in-furrow), however, have seemingly performed an insecticide-resistance-management role very well. Because only a portion of larvae are exposed to soil insecticides applied at planting, in-field refuges (untreated areas) have been used unwittingly by growers for decades. *These findings may have important implications for the use of transgenic hybrids for corn rootworm management, because refuges (nontransgenic areas of fields) treated with soil insecticides will offer root protection and plentiful adult survival. Unlike soil insecticides, transgenic hybrids that are designed to offer root protection against corn rootworm larvae will be powerful population suppression tools, lowering the general equilibrium position of the rootworm population across large numbers of acres.*

Ball and Su (1979) found that very low concentrations of carbofuran and carbaryl stimulated oviposition and increased longevity of western corn rootworm females. At very low percentages of LD_{50} values, western corn rootworm females treated with carbaryl or carbofuran had increased longevity and enhanced oviposition. No explanations were offered to explain the mechanism behind these observations. If western or northern corn rootworm females are exposed to less than a lethal dose of a toxic protein by feeding on a transgenic cultivar, will their longevity, emergence, and/or oviposition be affected? If so, would random mating be interfered with, possibly resulting in temporal asynchrony between (RR) homozygous resistant and (SS) homozygous susceptible adults? This question deserves consideration in the development of resistance development models for transgenic insecticidal cultivars.

Areawide Corn Rootworm Adult Suppression and Transgenic Insecticidal Cultivars

The concept of suppressing corn rootworm populations across a landscape has been discussed for over thirty years. The feasibility of an areawide suppression program for the western corn rootworm was evaluated for a 16-square mile area in Nebraska during August in 1968, 1969, and 1970 by applying ultra low volumes of malathion at 9.7 ounces of active ingredient per acre (Pruess et al. 1974). Densities of western corn rootworms were reduced in subsequent seasons by 39, 54, and 72%. A treatment threshold of one beetle per plant in mid-August was judged to be acceptable in preventing economic infestations of corn rootworm larvae. Pruess et al. (1974) offered the following thoughts regarding the success of the areawide approach: "The wide-area approach is justifiable only if the benefits derived are economically or biologically superior to presently utilized means of corn rootworm management. The program was successful to the extent that no economic infestations occurred in the treated area during any year following adult control while use of soil insecticides was virtually abandoned in that area. But this achievement was accomplished only by a greater total use of insecticide, applied to the total environment, without cumulative benefits. Results suggest that adult control is an alternative to soil insecticides and that treatment of selected fields is a promising approach, though our experiment was not designed to confirm this." Gray (1995) provided some background information regarding the interest in the areawide management concept for corn rootworms and cautioned that areawide management programs for corn rootworms should be conceptualized as only suppression efforts and not eradication attempts: "There are obvious and overwhelming obstacles suggesting that corn rootworms are not suitable candidates for an eradication program. Because corn rootworms occupy such an enormous geographical range in the U.S. (60 million acres of corn in the Corn Belt alone), extending from states such as Colorado to the east coast, an eradication effort would be futile."

For several years at this conference, summaries have been provided (Buhler et al. 1997, 1998) for a large coordinated USDA-ARS research effort among several states designed to evaluate the potential usefulness of SLAM (MicroFlo Company), an insecticidal bait that

contains cucurbitacins and a low level of carbaryl, for the areawide suppression of corn rootworms. The insecticidal bait is being evaluated at four 16-square mile experimental sites and one 8-square mile location. The states involved are Illinois, Indiana, Iowa, Kansas, South Dakota, and Texas. One of the test sites overlaps the state border of Illinois and Indiana. During the summer of 1997, aerial treatments of SLAM were applied for the first time in all experiments. In 1998, the efficacy of these areawide broadcast applications was evaluated by examining root injury in producers' fields. Unlike the use of soil insecticides applied at planting, areawide corn rootworm suppression programs may not be as compatible with transgenic insecticidal cultivars from a resistance management viewpoint. Both transgenic hybrids and areawide management efforts would serve to lower the general equilibrium position of corn rootworm populations. Although soil insecticides may confer root protection, they generally do not reduce emergence of adults, and, in certain years may actually increase overall survival to adulthood. Conversely, fewer beetles would emerge across a landscape in which areawide suppression programs and transgenic cultivars are used, eventually, shrinking the number of susceptible alleles available for mixing with those that may convey resistance to transgenic corn rootworm hybrids.

Conclusions

If transgenic insecticidal cultivars become available for corn rootworm control, their adoption by farmers is expected to be much swifter compared with purchases of transgenic hybrids for the management of the European corn borer. Most farmers, particularly those who produce continuous corn, annually use soil insecticides for corn rootworms as a regular part of their corn production system. Historically, because most producers have not allocated resources for the management of European corn borers, the purchase of a transgenic hybrid represents a new input cost in the production of a given crop. The economic scenario for corn rootworm management could not be more different. Because of the anticipated large-scale adoption of transgenic insecticidal cultivars for corn rootworm control, considerable coordinated efforts on the part of industry and universities will be required in the development of effective resistance management plans. This paper may serve as a catalyst for further discussions on the development and implementation of resistance management plans for the use of transgenic insecticidal cultivars for corn rootworms.

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SOYBEAN VARIETAL RESPONSE TO SULFENTRAZONE

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Sulfentrazone, a new herbicide developed for use in soybean [*Glycine max* (L.) Merrill] and tobacco (*Nicotania* spp.) , has been recently introduced into the major soybean-producing areas of the Midwest. Sulfentrazone is a member of the aryl triazolinone herbicide family (Theodoridis et al. 1992). Its mode of action is similar to that of the diphenyl ether herbicides in that it inhibits protoporphyrinogen oxidase (PPO) (Nandihalli and Duke 1993). Protoporphyrinogen oxidase oxidizes protoporphyrinogen to protoporphyrin IX in the chlorophyll biosynthetic pathway, and it is the buildup of this intermediate material that results in cell membrane disruption and subsequent plant death (Becerril and Duke 1989a, b). Most weeds are killed as they emerge from the soil and are exposed to sunlight.

Sulfentrazone exhibits excellent preemergence soil activity and is active on many of the problem small-seeded broadleaf weeds common to soybean production across the Midwest, including common lambsquarters and the pigweed species complex. Sulfentrazone also suppresses a number of grass species and has value from a weed-resistance-management standpoint in the control of ALS-resistant biotypes of some problem weed species. For these reasons, sulfentrazone has often been applied alone or in combination with other soil-applied products, such as chlorimuron-ethyl or clomazone, as early preplant (EPP), preplant incorporated (PPI), or preemergence (PRE) applications in both no-till and conventional-till soybean production.

Throughout the initial field testing and recent commercialization of sulfentrazone many studies, both field and laboratory, reported differences in sensitivity of soybean cultivars to sulfentrazone (Swantek and Oliver 1996; Dayan et al. 1997; Zhaohu et al. 1997). Historically, soybean cultivars have shown differing responses to many commonly used herbicides. Wax et al. (1976) and De Weese et al. (1989) found that soybean cultivars varied greatly in response to metribuzin and that cultivars could be categorized as either tolerant or sensitive to metribuzin. Kent et al. (1998) and Wixson and Shaw (1991) found differing soybean cultivar responses to applications of the imidazolinone herbicides imazaquin and imazethapyr.

Soybean seedling injury in the field associated with applications of sulfentrazone is similar to that of injury from other soil-applied soybean herbicides. Some common symptoms of soybeans injured by sulfentrazone applications include callusing of the hypocotyl arch, and in extreme cases hypocotyl abortion, callusing of the soybean stem at the soil surface, shortened internodal length, speckling or necrosis of leaf tissue, and an overall slowed early-season growth rate. The risk of soybean injury from applications of sulfentrazone, as with most soil-applied herbicides, appears to be linked to adverse environmental conditions that lead to poor soybean growth and development. Slow soybean emergence through cool, wet soils treated with sulfentrazone can increase the risk of seedling injury due to high levels of available sulfentrazone and increased contact time with the herbicide. Sulfentrazone application timings at soybean emergence or just prior to emergence also increase the risk of injury to soybean compared with earlier applications due to concentrated levels of herbicide in the soybean germination zone. Low organic matter or sandy soils can increase the risk of injury due to lower sulfentrazone adsorption to the soil.

To date there is limited information available on the mechanisms of soybean tolerance to sulfentrazone, the

genetically mediated components of cultivar tolerance to sulfentrazone, and environmental and edaphic conditions associated with soybean injury resulting from applications of sulfentrazone. If environmental conditions conducive to sulfentrazone injury occur, it would be beneficial to producers to have planted the most tolerant cultivars. The objective of this study was to evaluate the sensitivity of selected current cultivars and the major ancestors of current soybean cultivars to a preemergence application of sulfentrazone under controlled conditions.

Materials and Methods

Ancestor soybean cultivars were selected for the sulfentrazone tolerance experiment on the basis of their relative importance of use in soybean breeding programs resulting in modern soybean lines. Gizlice et al. (1994) identified 35 extant ancestors and 1st progeny of public North American cultivars that account for over 95% of the genes in current soybean cultivars. These ancestral lines, plus selected current cultivars, were tested for tolerance to a soil-applied application of sulfentrazone (Table 1). The soybean cultivars were provided by the USDA Soybean Germplasm Collection, Urbana, IL.

Soybean seeds were planted at a depth of 2 cm in plastic 650-ml square containers containing a standard greenhouse soil consisting of a 1–1–1 mix of soil, torpedo sand, and peat. The pots were placed in a growth chamber and watered to adequately moisten the soil and stimulate the germination of soybean seeds. Formulated sulfentrazone (75 DF) was applied to the soil surface preemergence 1 d after planting by using an Allen Track™ spray chamber set to deliver 20 gpa. Sulfentrazone was applied at the rate of 0.25 lb a.i./A to the soil surface. Conditions in the

Table 1 • Ancestor and public soybean cultivars used in sulfentrazone tolerance experiment.

Cultivar	Maturity group	Origin[1]	% parentage of modern cultivars[2] Northern varieties	Southern varieties
Lincoln	III	China ?	24.16	2.90
PI 88788	III	China	0.38	0.74
Richland	II	China	11.31	0.81
Manitoba Brown	00	Canada	1.50	0.0
A.K. (Harrow)	III	China	6.88	0.0
Fiskeby III	00	Sweden	0.72	0.0
Haberlandt	VI	N. Korea	0.13	2.50
Jogun	III	N. Korea	0.76	0.0
Kanro	II	N. Korea	1.03	0.0
(FiskebyV)	000	Sweden	0.52	0.0
Bansei	II	Japan	1.10	0.0
Ralsoy	VI	N. Korea	0.08	1.93
Mandarin (Ottawa)	0	China	17.23	0.0
S-100	V	China	1.75	21.31
Flambeau	00	Russia	0.97	0.0
Capital	0	China	2.37	0.0
Fiskeby V	000	Sweden	0.52	0.0
Mejiro	IV	Japan	0.0	2.30
CNS	VII	China	2.98	24.71
Arksoy	VI	N. Korea	0.04	1.67
Mukden	II	China	4.91	0.0
Dunfield	III	China	3.51	3.86
Illini	III	China	3.10	0.04
PI 71506	IV	China ?	0.14	0.33
Fiskeby 840-7-3	00	Sweden	1.10	0.0
Peking	IV	China	0.10	1.14
Perry	IV	China ?	2.08	2.06
Korean	II	N. Korea	0.76	0.0
Roanoke	VII	China	0.24	6.54
Ogden	VI	Japan ?	4.31	6.44
Anderson	IV	—	1.18	0.70
FC 31745	VI	—	0.03	1.19
Improved Pelican	VIII	—	0.0	1.74
Jackson	VII	—	0.18	10.61
Ransom	VII	—	—	—
Cobb	VIII	—	—	—
Elgin	II	—	—	—
Thorne	III	—	—	—
Strain No. 18	0	—	—	—
Hutchison	V	—	—	—
Bilomi #3	X	—	—	—
Gasoy 17	VII	—	—	—
Tracy-M	VI	—	—	—

[1] Origin given if known.

[2] Describes the relative influence each ancestor cultivar has had in breeding programs used to develop modern cultivars grown in the northern and southern regions of the United States

growth chamber were maintained on 16-h d, with a daytime temperature of 82° F and nighttime temperature of 73° F. Relative humidity in the growth chamber was maintained between 70-80%. The soybean seedlings were watered and fertilized from above as needed.

Visual ratings of soybean injury were made 14 d after treatment compared with the respective untreated plants for each cultivar. Plant height measurements also were taken 14 d after treatment. Soybean plants were harvested and aboveground dry biomass measurements were made after drying the plants in a Precision™ mechanical convection oven at 104° F for 72 h.

Results and Discussion

The soybean cultivars grown under controlled conditions exhibited varying degrees of sensitivity to the preemergence application of sulfentrazone. At the application rate of 0.25 lb of a.i./A, that is comparable or slightly greater than commonly recommended field use rates, differences in visual injury, height, and dry biomass were evident between cultivars. Based on these differences it became apparent that some cultivars are tolerant to sulfentrazone, whereas others are relatively sensitive to preemergence applications. As a result we classified the cultivars tested either as tolerant, sensitive, or intolerant to sulfentrazone (Table 2).

Among the ancestor cultivars, there was a tendency toward more injury among the southern varieties compared with the earlier maturing, more northern varieties. Whether or not this tendency is of value in trying to predict which modern cultivars will show sensitivity to sulfentrazone remains to be determined. Many of the cultivars used currently in production have many common ancestors and it is difficult to quantify just how much influence, in terms of specific herbicide tolerance, one ancestor line has had over another. This problem continues to be the focus of ongoing field research by many investigators. Recent evidence suggests that tolerance to sulfentrazone may be controlled by a single gene, with tolerance being dominant over susceptibility (Swantek et al. 1998). Injury has not been confined to just the southern varieties; commonly grown northern varieties also have experienced injury. Area seed and herbicide companies recognized the need to complete similar screening projects by using their soybean cultivars and have made available their lists of soybean lines that show varying levels of tolerance to sulfentrazone applications.

Many factors can contribute to soybean injury associated with the use of a soil-applied herbicide, including

Table 2 • Soybean cultivar response to preemergence application of sulfentrazone.

Cultivar	% Injury[1]	% Height reduction[2]	% Biomass reduction[3]
Intolerant			
Tracy-M	53	71	33
Gasoy 17	51	68	31
Bilomi # 3	53	66	48
Jackson	48	64	30
Cobb	40	60	19
Ransom	43	60	28
Improved Pelican	50	56	32
FC 31745	38	52	27
Ogden	33	50	11
Hutcheson	45	47	9
Roanoke	35	46	22
Korean	40	41	11
Sensitive			
Perry	25	38	22
Peking	13	30	21
Fiskeby 840-7-3	16	29	17
CNS	17	22	7
Anderson	12	21	18
Dunfield	20	14	4
Bansei	22	13	0
PI 71506	21	12	0
Illini	7	12	7
Mejiro	13	11	8
Mukden	6	11	4
(Fiskeby V)	17	10	9
Arksoy	11	10	0
Capital	10	10	17
Tolerant			
Thorne	6	9	0
Flambeau	18	9	13
Strain No. 18	11	9	13
Ralsoy	18	8	0
S-100	10	7	3
Kanro	1	5	0
Fiskeby V	6	5	5
Jogun	14	5	0
Haberlandt	18	2	15
Fiskeby III	5	2	0
A.K. (Harrow)	3	2	0
Manitoba Brown	3	0	0
PI 88788	5	0	0
Richland	9	0	0
Lincoln	10	0	0

[1]Visual rating of injury made 14 days after treatment (DAT) comparing treated and untreated plants of each cultivar. Expressed as percent injury, and based on general seedling development, leaf chlorosis, and overall plant vigor.

[2]Height measurement taken 14 DAT comparing treated and untreated plants of each cultivar.

[3]Dry matter reduction of treated plants 14 DAT compared with untreated plants for each cultivar.

poor soybean growing conditions; cool, wet, or compacted soils; and application timing. Good management options exist, however, for soybean growers who use sulfentrazone as a part of their overall weed management plan. By avoiding the use of the most sensitive varieties, the risk of early-season injury and potential yield reduction can be minimized. Coupled with appropriate soybean cultivars, sulfentrazone continues to be an excellent fit in weed control programs across many areas of the Midwest.

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WEED COMPETITION IN CORN

James J. Kells

Weeds compete with corn (*Zea mays* L.) for moisture, nutrients, and light and can significantly reduce yields. The extent of yield loss from weeds, however, varies widely from site to site and is affected by several factors. To better understand the impact of weeds on corn yield, several studies have been conducted during the past decade.These studies have focused on weed density and weed duration.

Weed Density

Studies have been conducted to measure yield loss from a specific weed species at a range of densities. The regional research project NC-202 has focused on velvetleaf, giant foxtail, and common lambsquarters. The velvetleaf data serves as a good example. Studies were conducted in Michigan, Nebraska, South Dakota, and Colorado and the data were summarized across states and years (Lindquist et al. 1996). Corn yield loss from 6 velvetleaf plants per foot of row varied from <20% to >80% among the 11 studies conducted between 1988 and 1994. In Michigan, giant foxtail at 20 plants per foot of row reduced corn yield by ≈25% in 1994 and 40% in 1995 (Fausey et al. 1997). These highly variable results demonstrate the effect of the environment and other factors on yield loss from weed competition.

Rainfall patterns vary greatly from year to year and from site to site. These differences in rainfall certainly account for much of the variation in yield loss from weeds. The relative time of weed emergence also affects weed competitiveness. Weeds that emerge even a few days later than the crop are less competitive than weeds that emerge with the crop.

Soil-applied herbicides also can affect the competitiveness of weeds. Research in Michigan has shown that velvetleaf in sites treated with atrazine or Prowl grew slower, produced less seeds, and were less competitive with corn (Schmenk and Kells 1998).

The variability of crop response to weeds, related to environmental and other factors, makes predicting yield loss from a specific weed density very difficult. More research is needed to better understand the effect of the environment on yield loss from weeds before predictive models will be reliable.

Weed Duration

The introduction of Liberty Link and Roundup Ready corn has focused attention on the question, How long can I wait to treat without suffering a yield loss from weed competition? There is a great deal of confusion regarding the answer to this question. Furthermore, there has been very little research conducted on this question. In 1998, most universities in the Corn Belt initiated research on the effect of Roundup Ultra application timing on corn yields. Over the next 1 to 2 yr, the base of data from these studies will be very useful in understanding the risks of delayed herbicide application in corn.

A study was conducted in 1992 and 1993 in Michigan that provided some interesting information on the issue of postemergence herbicide timing (Carey and Kells 1995). They planted corn into a field with high weed density following conventional tillage. Weeds were removed when they reached 2, 4, 6, or 8 in. in height with a tank mixture of Accent plus Buctril. The corn height, corn leaf stage, and days after planting for each

Table 1 • The effect of weed removal time on yield loss in corn, Michigan State University, 1992 and 1993.

	Herbicide application timing			
Weed height (in.)	Corn height (in.)	Corn leaf stage (collars)	Time after planting (d)	Corn yield loss (%)
1992				
2	3	2	12	0
4	6	3	18	0
6	12	5	25	10
8	18	6	31	20
weedy	—	—	—	68
weed free	—	—	—	0
1993				
2	4	2	9	0
4	6	3	15	0
6	12	4	20	0
8	18	4	23	8
weedy	—	—	—	49
weed free	—	—	—	0

Data from Carey and Kells (1995).

treatment timing are summarized in Table 1. The spring of 1993 was warmer than that of 1992 and the weeds reached each application timing earlier in 1993. Corn height for each application timing was similar between the 2 yr. For example, when weeds were 6 in. in height, corn was 12 in. in height both years. Corn leaf stages (leaves with collars), however, advanced more rapidly in 1992 than in 1993. For example, 18-in. corn in 1992 had 6 leaves with collars, whereas 18-in. corn in 1993 had only 4 leaves with collars.

In 1992, no yield loss occurred if weeds were treated at or before 4 inches in height. When weeds were treated at 6 in. or 8 in., corn yield loss was 10 and 20%, respectively. If weeds were not removed (no herbicide application), 68% yield loss occurred. In 1993, no yield loss occurred when weeds were treated at or before 6 in. in height. When weeds were treated at 8 in., yield loss was 8%. Where weeds were not treated, 49% yield loss occured.

This study was conducted under weed densities higher than that which is usually found in commercial fields. Yield losses without herbicide application were ≥49%, indicating intense weed competition. No yield loss occured until weeds were allowed to grow to 6 in. in 1992 and 8 in. in 1993. These data suggest that if annual weeds are treated before they exceed 4 in. in height, yield loss from early-season weed competition is unlikely.

Although the weeds in this study were killed with herbicides other than Roundup Ultra or Liberty, the results give an indication of the risk of yield loss from delayed herbicide applications in Roundup Ready or Liberty Link corn. Data generated across the Corn Belt in 1998 and 1999 will further clarify the effect of herbicide treatment time on yield loss from weed competition in corn.

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PERSISTENCE OF SOIL-APPLIED HERBICIDES

Bill Simmons

Soil-applied herbicides are used alone or in conjunction with a postemergence applied herbicide to control weeds until the crop canopy closes. The period of time where weed control is needed varies depending upon the crop, time of herbicide application, row-spacing, growing conditions, and other factors. For a soil-applied herbicide to be economically viable within a given cropping system, it must provide value to the producer by eliminating or reducing weed competition effects on yield above and beyond what a postemergence application alone will provide.

The need for residual weed control from a soil-applied herbicide is generally greater for corn than soybeans, and more important with wide versus narrow rowed crops. Additionally, residual herbicides may be important when late season weed species are present that can germinate beneath crop canopies.

Factors Affecting Persistence

Herbicide structural properties of the parent molecule influence degradation rates under field conditions. Although persistence is an important determinant of "extended" weed control, it is not the only important factor. The efficacy of a herbicide is the resultant product of persistence (how much herbicide is present at a given time), sorption (how much herbicide is in the soil solution) and activity (toxicity of a herbicide on different species). Herbicide loss pathways in soil are microbial and chemical, driven primarily by reactions with water. Soil temperature and moisture effects on herbicide degradation that utilize microorganisms operate best at optimum biological growth conditions. Non-biological chemical reactions are typically enhanced with increased temperature. Water is essential for microbial activity and increases aerobic processes until saturation hampers gas transfer with the atmosphere. Soil texture and organic matter content have a small effect on carryover because the differences in water and nutrient availability are often counter balanced by the difference in herbicide adsorption. Thus, a fertile soil, rich in organic matter, may promote faster degradation of a herbicide but also have less available to degrade based on its greater adsorption sites.

Grass Control in Corn

Herbicide applications continue to get earlier. Several herbicides have fall application labels. Two relatively new entrants to the corn market are Axiom®, a mix of fluthiamide (proposed name) and metribuzin and a new encapsulated formulation of acetochlor MON58430. Both of these herbicides will have utility in the early preplant market based on the longevity of control seen in field trials and in our greenhouse bioassay studies. Applying a herbicide 0 to 30 days before planting is motivated by two factors: 1) spreading work loads out over a manageable time period, and 2) to increase the chances of a herbicide incorporating rain before weed germination occurs. Applications earlier than 30 days before planting are used primarily to spread the work load or to reduce the need for a planting burndown herbicide application. Fall herbicide applications are performed for convenience or to take advantage of a planned trip across a field to apply fertilizer. For a fall application to be effective, it needs to be sprayed before soil freezing to minimize degradation before planting. A warm winter or extended wet period in the spring may

decrease the efficacy of a fall herbicide application. Fields treated with herbicides in the fall are often tilled shallowly prior to planting in the spring.

In work reported at previous conferences, we have shown that acetchlor and dimethenamid have greater activity at lower soil water contents than did metolachlor. However, metolachlor typically provided longer control under field conditions. Herbicide properties that slow degradation may reduce the availability of a compound in soil solution and thus, lower efficacy under dry soil conditions.

Strategies to Prolong Herbicide Activity

Some soil-applied herbicides may be used in split-applications. A second application is accompanied by a postemergence product that kills existing weeds. By applying some of the residual herbicide early, the efficacy can be extended beyond that offered by a preplant or early preplant application. This strategy enhances the performance of soil-applied herbicides currently available for grasses and may be particularly effective in transgenic corn systems where there are planned early post and post applications.

Herbicide encapsulation may serve to escort herbicides through crop residue then release them into the soil or provide a metered release that is affected by moisture, temperature, or microbial activity. Two encapsulation formulations are available for acetochlor and continued research will determine the encapsulation characteristics of each. Previous work with starch encapsulation of atrazine promoted excessive persistence and resulted in carryover injury to soybean. The two commercially available encapsulated formulations of acetochlor are unlikely to have carryover problems; however, their performance in dry soil conditions will need further evaluation.

The goal of all farmers, dealers, and applicators should be to put a herbicide of their choice into the most favorable conditions to enhance maximum performance. Rainfall timing, precipitation amounts, and soil temperatures are not controllable factors. Application timing and split application strategies are under an applicator's control and both can have a strong influence on herbicide efficacy.

Perennial Weed Management in Roundup Ready Soybeans

Jerry Doll

Glyphosate has been a useful tool for perennial weed management for many years. It has been applied in soybean [*Glycine max* (L.) Merrill] production systems as either a fall or spring treatment before planting, as a spot treatment or via selective applicators in the growing crop, and as a preharvest treatment. The recent development and commercialization of glyphosate-resistant crops allow us to apply glyphosate selectively in the growing crop. This new use of glyphosate will revolutionize our ability to manage several perennial weeds, especially broadleaf species with spreading root systems such as hemp dogbane (*Apocynum cannabium*), common milkweed (*Asclepias syriaca*), Canada thistle *(Cirsium arvense)*, perennial sowthistle (*Sonchus arvensis*), Jerusalem artichoke (*Helianthus tuberosus*) and field (*Convolvulus arvensis*) and hedge bindweed (*Calystegis sepium*). These weeds can be persistent in all tillage systems. The development of glyphosate-resistant crops opens the door for us to apply a highly systemic herbicide at the ideal growth stage of the perennial weed at the optimum rate, and with essentially no risk of crop injury and still have crop competition to further weaken the weed infestation.

Objectives and Hypotheses

We have researched perennial weed management in glyphosate-resistant soybeans since 1995 to determine to find the most effective time and rate of glyphosate application to control three perennial broadleaf weeds. We speculated that the maximum labeled rate in glyphosate-resistant soybeans at that time (1.5 lb a.i./A) would provide effective control because we could time the application to match the period of active translocation from the foliage to the underground plant system, and we would have crop competition to further inhibit weed growth and development. We also hypothesized that not all perennial broadleaf weeds would be controlled by the same rate of glyphosate because the perennial section of the label indicates that some weeds may be controlled by 1.5 lb/A of glyphosate (Canada thistle) whereas others may need 3.0 lb/A (hemp dogbane).

Most of the soybeans grown in Wisconsin are planted in narrow rows to maximize the yield potential. Narrow row spacing also enhances the competitive advantage of soybeans with weeds by shading the soil surface sooner than if the crop is planted ≥20-in rows. Also, many of our soybeans are planted without tillage, offering a distinct advantage to maximize the effectiveness of glyphosate on perennial weeds for 2 reasons. First, in no-till systems weed growth is uninterrupted and the weeds reach more advanced growth stages sooner than if tillage was performed. Thus, perennials reach the bud to early-flower stage earlier than if tillage was done, and because translocation to the root is maximized during these stages, the best long-term control should result in a no-till system. Second, the absence of tillage helps ensure that the root system is intact and that most of the belowground system will have the chance to receive glyphosate from treated shoots.

Methods

All trials were conducted on grower fields in Wisconsin. In 1995 and 1996 we evaluated glyphosate as a management tool on hemp dogbane and wirestem muhly

(*Muhlenbergia fronderosa*) in glyphosate-resistant soybeans. In 1997 and 1998 we conducted similar trials on Canada thistle and common milkweed.

All trials were planted by the producer at the time they normally plant. For the reasons mentioned, all trials were done in narrow row, no-till soybean production systems. Either a burn down herbicide application or a shallow disking was done to kill emerged annual weeds before planting. Annual weeds pressure was generally light to moderate at all sites and these species were controlled by preemergence herbicide treatment that had no effect on the perennial species being studied, application of postemergence graminicide for annual grass control, or by hand weeding in the check plots. The glyphosate treatment for the perennial weeds also killed the annuals and no subsequent flushes of annual weeds were observed.

Glyphosate was applied in 15 to 18 gal/A of water with a CO_2 backpack sprayer fitted with extended range flat fan nozzles. Applications were made at predetermined growth stages of the weed. These applications were generally timed to be when the weed was in the late vegetative to bud stage and in the early- flowering stage. Rates of glyphosate applied were 0.56, 0.75, 1.125, and 1.5 lb a.i./A (these rates correspond to 1.5, 2, 3, and 4 pt/A of Roundup) in single applications and combinations of the lower rates as repeated applications (the 2nd application usually applied 7 to 14 d after the first). A nonionic surfactant was added (0.50%, vol:vol) to the spray solution in 1995 but not in 1996-1998 when the newer formulation of glyphosate (Roundup Ultra) became available.

Control ratings were taken from 30 to 40 d after the 1st application and reinfestation ratings were taken at the end of the growing season and again in June of the following year. Weed populations the year after application also were determined.

Results with Hemp Dogbane

Our research began with hemp dogbane because this weed has increased in distribution and density in many areas of Wisconsin and there are almost no herbicides that reduce its competitiveness in soybean. This North American native grows quickly in the absence of tillage. Hemp dogbane emerges over an extended period, thus complicating application timing. For this and the other perennials studied in this project, from 25 to 50% of the plants were at the indicated growth stage at the time of application.

In 1995 hemp dogbane was treated at 4 growth stages (Table 1). When treated in the vegetative growth stage, visual control from 45 to 60 d after application was poor. The degree of control increased and the level of reinfestation decreased when glyphosate was applied to hemp dogbane in the bud stage, but the greatest response occurred with glyphosate applied to hemp dogbane in the early- and full-flower stages. Even the lowest rate tested (0.56 lb/A) prevented late-season reinfestation in 1995 when applied to fully flowered hemp dogbane in early July. Sequential applications of glyphosate to hemp dogbane that started with hemp dogbane in the early-bud stage gave control similar to that of single applications made in the early- and full-flower stages. When sequential applications started in the vegetative stage, control was reduced, especially for the dogbane population the following year. The level of hemp dogbane pressure at the end of the season of application correlated reasonable well with the dogbane pressure and population in 1996 but the fall pressure tended to overestimate the level of long-term control achieved.

Based on the 1995 trial, only 2 treatment times were used in 1996. Hemp dogbane control from 25 to 50 d after application was very good to excellent for all rates at both times of application. Control ratings varied more than usual between treatments. Part of this variation could have resulted from the bacterial disease on the hemp dogbane foliage that may have reduced glyphosate translocation to the roots. The variable pattern of infection in July probably affected the visual ratings taken after application. The bacterial infection defoliated dogbane in the check plots by mid-to late August and thus no early-fall ratings were taken in the 1996 trial. The hemp dogbane infestation the year after treatment in the 1996 trial was greater than in the 1995 trial. High infestation also may be due to the bacterial infection noted in 1996.

Overall, the 1.125 and 1.50 lb/A rates of glyphosate applied to hemp dogbane in the early- to full-flower growth stages approached eradication after a single use in glyphosate resistant soybeans. The Roundup label recommends 8 pt/A (3.0 lb a.i.) for hemp dogbane control. Our data suggest that 3 pt/A may be adequate in many situations.

Results with Canada Thistle

Canada thistle populations also have increased noticeably in Wisconsin in recent years. The 1997 site had a moderate Canada thistle infestation and both the

Table 1 • Hemp dogbane control in glyphosate resistant soybeans.

Glyphoste rate (lbae/acre)	Year applied	Time applied (dap[1])	Soybean growth stage	Weed growth stage	Hemp dogbane Control (%) 25–50 daa[2]	Pressure (%)[3] Fall	Summer	Pop. next yr. (no./100 ft²)
0.56	1995	24	unif	veg	22	72	22	76
0.75	1995	24	unif	veg	58	36	9	33
1.125	1995	24	unif	veg	43	33	12	,41
1.50	1995	24	unif	veg	57	26	6	22
0.56	1995	31	1 trif	e bud	73	4	6	20
0.75	1995	31	1 trif	e bud	72	12	6	23
1.125	1995	31	1 trif	e bud	91	8	4	13
1.50	1995	31	1 trif	e bud	78	10	3	9
0.56	1995	37	2–3 trif	e flow	64	12	6	31
0.75	1995	37	2–3 trif	e flow	93	4	2	5
1.125	1995	37	2–3 trif	e flow	92	4	1	3
1.50	1995	37	2–3 trif	e flow	100	1	2	5
0.56	1995	50	5–9 trif	flow	88	0	1	2
0.75	1995	50	5–9 trif	flow	99	0	2	5
1.125	1995	50	5–9 trif	flow	100	0	1	4
1.50	1995	50	5–9 trif	flow	100	0	0	2
.38/.38	1995	24/37	—	—	92	3	5	24
.38/.38	1995	37/50	—	—	82	2	1	3
.75/.75	1995	24/37	—	—	98	1	5	17
.75/.75	1995	37/50	—	—	96	2	1	5
Check	1995	—	—	—	0	76	38	118
LSD (10%)	1995	—	—	—				
0.56	1996	34	1—2 trif	e bud	96	—	9.7	16.3
0.75	1996	34	1–2 trif	e bud	82	—	5.0	9.7
1.125	1996	34	1–2 trif	e bud	83	—	4.7	7.0
1.50	1996	34	1–2 trif	e bud	82	—	7.3	15.0
0.56	1996	42	3 trif	e flow	83	—	2.0	4.7
0.75	1996	42	3 trif	e flow	81	—	12.7	21.3
1.125	1996	42	3 trif	e flow	99	—	2.0	3.7
1.50	1996	42	3 trif	e flow	98	—	1.3	3.7
.38/.38	1996	34/42	—	—	95	—	1.7	6.0
.56/.56	1996	34/42	—	—	93	—	4.0	6.0
.75/.75	1996	34/42	—	—	78	—	10.0	20.9
Check	1996	—	—	—	0	—	14.3	28.3
LSD (10%)	1996	—	—	—	21	—	15.6	15.2

[1] dap,days after planting;

[2] daa, days after application.

[3] pressure = level of weed infestation; summer evaluation taken in June in the next crop (usually corn).

thistles and annual broadleaves emerged before planting in May. Rather than use a burn down treatment that would have affected the Canada thistles, the field was lightly disked and then planted. Plots with light Canada thistle infestations were designated as the check plots to minimize the level of infestation in the field for the producer the following season. Thistle density doubled in the checks from June to late September (initial density data not shown). Glyphosate gave excellent control of Canada thistle at nearly all rates and times of

Table 2 • Canada thistle control in glyphosate resistant soybeans.

Glyphoste rate (lbae/acre)	Year applied	Time applied (dap[1])	Soybean growth stage	Weed growth stage	Canadian thistle Control (%) 30–40 daa[2]	Pressure (%)[3] Fall	Pressure (%)[3] Summer	Pop. next yr. (no./100 ft²)
0.56	1997	25	1 trif	e bud	77	3.0	3.0	3.9
0.75	1997	25	1 trif	e bud	95	1.0	0.3	.2
1.125	1997	25	1 trif	e bud	100	0	0	0
1.50	1997	25	1 trif	e bud	100	0	0	0
0.56	1997	36	3–4 trif	e flow	100	0	0	0
0.75	1997	36	3–4 trif	e flow	100	0	0	0
1.125	1997	36	3–4 trif	e flow	100	0	0	0
1.50	1997	36	3–4 trif	e flow	100	0	0	0
.38/.38	1997	25, 36	—	—	100	0	0	0
.56/.56	1997	25, 36	—	—	100	0	0.3	.2
.75/.75	1997	25, 36	—	—	100	0	0	0
Check	1997	—	—	—	0	12.7	12.0	35.6
LSD (10%)	1997	—	—	—	13	2.8	3.6	10.1
0.56	1998	44	3–4 trif	e bud	84	1.7	—	—
0.75	1998	44	3–4 trif	e bud	98	0	—	—
1.125	1998	44	3–4 trif	e bud	99	1.7	—	—
1.50	1998	44	3–4 trif	e bud	100	0	—	—
0.56	1998	55	6–7 trif	bud	82	0	—	—
0.75	1998	55	6–7 trif	bud	87	1.0	—	—
1.125	1998	55	6–7 trif	bud	97	0	—	—
1.50	1998	55	6–7 trif	bud	99	1.0	—	—
.38/.38	1998	44, 55	—	—	98	2.3	—	—
.56/.56	1998	44, 55	—	—	98	2.0	—	—
.75/.75	1998	44, 55	—	—	99	0	—	—
Check	1998	—	—	—	0	11.7		
LSD (10%)	—	—	—	—	16	6.6	—	—

[1] dap, days after planting;

[2] daa, days after application.

[3] pressure = level of weed infestation; summer evaluation taken in June in the next crop (usually corn).

application, including the early application at 1.125 and 1.5 lb/A in the 1997 trial (Table 2). The 0.56 and 0.75 lb/A rates applied to thistles in the early-flower stage, however, also appeared to eradicate thistles in just a single season of glyphosate-resistant soybeans.

Results were similar in the 1998 trial. At this site, the producer has a long history of no-tillage production and a combination of glyphosate and 2-4-D ester was applied as a burn down treatment after some of the Canada thistles had emerged. This treatment significantly delayed the growth and development of the thistles. The 1st glyphosate application was made 44 d after planting when thistles had just started to form buds; the 2nd application date was 55 d after planting and still no thistles had reached the flowering stage. We treated because had we waited longer, the soybean canopy would have covered much of the Canada thistle foliage, reducing the level of control. The results show that excellent Canada thistle control resulted for all rates and both application times. Evaluations yet to be taken in 1999 will determine if the long term effects are similar over application dates and rates. As for hemp dogbane, there was no advantage of split applications of glyphosate to control Canada thistle in either year.

Our results show that Canada thistle is more sensitive to glyphosate than is hemp dogbane. This finding is

Table 3 • Common milkweed control in glyphosate resistant soybeans.

Glyphoste rate (lbae/acre)	Year applied	Time applied (dap[1])	Soybean growth stage	Weed growth stage	Common milkweed Control (%) 30–45 daa[2]	Pressure (%)[3] Fall	Pressure (%)[3] Summer	Pop. next yr. (no./100 ft^2)
0.56	1997	30	1–2 trif	e bud	33	9.0	6.7	13.5
0.75	1997	30	1–2 trif	e bud	59	9.0	6.3	11.1
1.125	1997	30	1–2 trif	e bud	70	4.3	3.7	7.5
1.50	1997	30	1–2 trif	e bud	50	9.3	5.7	9.5
0.56	1997	39	3–4 trif	e flow	72	2.0	1.7	3.4
0.75	1997	39	3–4 trif	e flow	75	1.3	1.3	0.6
1.125	1997	39	3–4 trif	e flow	96	6.3	4.3	6.0
1.50	1997	39	3–4 trif	e flwo	99	1.3	1.7	2.2
.38/.38	1997	30, 39	—	—	65	3.0	3.0	4.0
.56/.56	1997	30, 39	—	—	89	4.0	3.0	4.2
.75/.75	1997	30, 39	—	—	88	4.3	2.3	4.5
Check	1997	—	—	—	0	11.3	10.3	11.2
LSD (10%)	1997	—	—	—	25	6.4	4.9	8.8
0.56	1998	28	1–2 trif	e bud	68	6.0	—	—
0.75	1998	28	1–2 trif	e bud	97	4.7	—	—
1.125	1998	28	1–2 trif	e bud	100	1.7	—	—
1.50	1998	28	1–2 trif	e bud	97	4.3	—	—
0.56	1998	43	4–5 trif	flow	75	2.3	—	—
0.75	1998	43	4–5 trif	flow	78	2.7	—	—
1.125	1998	43	4–5 trif	flow	90	0	—	—
1.50	1998	43	4–5 trif	flow	91	1.0	—	—
.38/.38	1998	28, 43	—	—	92	0	—	—
.56/.56	1998	28, 43	—	—	95	0.3	—	—
.75/.75	1998	28, 43	—	—	97	0.7	—	—
Check	1998	—	—	—	0	17.3	—	—
LSD (10%)	—	—	—	—	17	4.6	—	—

[1] dap, days after planting;

[2] daa, days after application.

[3] pressure = level of weed infestation; summer evaluation taken in June in the next crop (usually corn).

consistent with the Roundup label guidelines that recommend 4 to 6 pt/A for Canada thistle control.

Results with Common Milkweed

In 1997, we also evaluated the effectiveness of glyphosate on common milkweed in a field with a light to moderate infestation. The site was disked lightly prior to no-till planting. We intentionally selected areas with low milkweed populations as the check plots to minimize the milkweed population left in the field when the trial was complete.

The data in Table 3 show that treating milkweed in the late-vegetative to early-bud stage (30 d after planting) was less effective (average of 53% control) than treating at the early-flower stage (average of 86% control). Glyphosate at rates of $\geq$1.125 lb/A applied to milkweed in the early-flower stage and when applied in split treatments gave the best control of treated plants. Some milkweed plants escaped control at each date because they emerged after the application. The later application, however, had less reinfestation than the early one (average of 3 plants per 100 ft^2 for the later application and 10 plants per 100 ft^2 for the early application). Split applications of glyphosate were no better than a single application in the early-flower stage.

Table 4 • Dates of application and crop growth stage in perennial broadleaf weed management trials in glyphosate resistant soybeans done in 1995–1998.

Year and trial	Planting date	Days after planting Early appl.	Days after planting Late appl.	Crop growth stage Early appl.	Crop growth stage Late appl.
95 Dogbane	May 16	31	37	1 trif	2–3 trif
96 Dogbane	May 17	34	42	1–2 trif	3 trif
97 Can. thistle	May 22	25	36	1 trif	4 trif
97 Milkweed	May 13	30	39	1–2 trif	3–4 trif
98 Can. thistle	May 9	44	55	3–4 trif	6–7 trif
98 Milkweed	May 20	28	43	1–2 trif	4–5 trif
Average		32	42	1.7 trif	4 trif

Summary

Overall control of the treated perennial broadleaf weeds in glyphosate-resistant soybeans was excellent and several treatment timings and rates approached eradication. Nonuniform emergence was especially noticeable with hemp dogbane and common milkweed. Canada thistle emerged both more uniformly and earlier than the other species studied.

The right time to treat perennial broadleaves is at the late-bud to early-flowering stage. This time is often 5 to 7 wk after planting when the soybeans are in the V-4 growth stage and is later than when annual weeds would normally be treated. This later timing, however, is consistently the best time for perennials because at this growth stage herbicide movement from the treated foliage to the roots is maximized.

A summary of the planting dates and application timings for all our trials on perennial broadleaf weeds with glyphosate-resistant soybeans in given in Table 4. We never determined the time to treat based on days after planting, and the days after planting when we made the early (usually bud stage) and late (usually early-flowering stage) applications show why. The number of days to reach these growth stages varies considerably across years, sites, and weeds. On average, the early applications were made 32 d after planting and the later ones at 42 d. Soybeans at these times were approaching the 2-trifoliate leaf stage for the early applications and averaged 4 trifoliate leaves for the later timing.

Based on these observations and other considerations, we have arrived at the following recommendations for perennial weed management in Roundup Ready soybeans.

1. Plant the crop without tillage. Tillage delays the development of perennial weeds, whereas in a no-till system, the weed grows rapidly and reaches the ideal growth stage for treatment sooner than if tillage was performed.
2. To avoid crop yield loss due to uncontrolled annual weeds while waiting to treat perennial broadleaves, apply a reduced rate (perhaps 50% of the recommended rate) of a soil-active herbicide as a tank mixture with the burn down treatment before planting. Select the preemergence herbicide(s) based on the expected annual weed population. A reduced rate is not risky because escaping annual weeds will be killed by the glyphosate application targeted to the perennial weed.
3. In fields with perennial broadleaf weeds where tillage has been done, apply a reduced rate of a preplant incorporated (PPI) or preemergence (PRE) herbicide. It may take longer for the perennial species to reach the flowering stage in these fields.
4. Delay the glyphosate application until the 1st flowers appear on the perennial broadleaf weed or until the weed is 24 to 30 in. in height whichever occurs first. It is unlikely that all plants will flower or be at the same height at the same time. Apply these guidelines to the most advanced plants in the population.
5. Application timing is more important than glyphosate rate. Our research has shown that applying glyphosate at 0.75 to 1.125 lb/A to actively growing perennial weeds in the early-flower stage gives excellent control the season of application, with greatly reduced weed populations the next year. This tactic illustrates the tremendous effect of

soybean competition on perennial broadleaves by not allowing the weed to replenish the root reserves before going dormant in the fall.

6. Split applications of glyphosate are not necessary. Control from a single treatment when perennial broadleaves begin to flower is as effective as repeated treatments. Thus no additional trips through fields with perennial broadleaf weeds should be needed because a well-timed, single postemergence application (following the burn down treatment with a residual product) gives maximum effect on the perennial weeds.
7. Uniform coverage of the weed foliage is important and difficult. As mentioned, weed height is seldom uniform in a population of perennial broadleaves. Select the appropriate nozzles and adjust the boom height to cover the weed foliage as uniformly as possible. Remember that boom height also affects the risk of particle drift from the target area.
8. Monitor the perennial weed populations in following years and use an appropriate management program if and when weeds subsequently reach threshold levels.

Additional Comments

We also have done trials on wirestem muhly in glyphosate-resistant soybeans and corn (*Zea mays* L.) with excellent results. In soybeans we approached eradication of rhizomatous wirestem muhly plants with a single application when wirestem muhly was 8 to 12 in. in height. This weed is less susceptible to glyphosate than quackgrass and also can reinfest from seed so it is important to monitor fields for several seasons to ensure that long-term success has been achieved. Quackgrass is effectively controlled by many postemergence herbicides in soybeans and by several in corn. We have recently conducted trials on quackgrass control in a glyphosate-resistant corn hybrid and the results are excellent with rates of 0.75 lb/A in both no-till and chisel-plowed systems.

A suggested program of perennial grass management in glyphosate-resistant crops is as follows:

> In no-till systems, apply the standard burn down treatment the producer already uses. Plant glyphosate-resistant soybeans and apply glyphosate at the appropriate time for annual weed control. This application should coincide with perennial grasses being 6 to 12 in. in height.
>
> In systems with tillage, simply plant glyphosate soybeans and apply glyphosate at the appropriate time for annual weeds. As in no-till systems, the perennial grasses should be 6 to 12 in. in height.

Our research to date has focused on single-season use of glyphosate in glyphosate-resistant crops. We now need information on the best systems to handle perennial weeds for the long term. Systems to test include the following: (1) single-season use of glyphosate in glyphosate-resistant crops; (2) alternate-year use of a glyphosate-resistant crops; (3) consecutive-year use of glyphosate-resistant crops (2, 3, or 4 season); and (4) alternate control strategies in rotation crops (e.g., clopyralid for Canada thistle control in corn in rotation with glyphosate in glyphosate-resistant crops). More research on the interaction of tillage with on perennial weed management in glyphosate-resistant crops also is needed.

WOOLLY CUPGRASS AND WATERHEMP: AN IOWA PERSPECTIVE

Micheal D. K. Owen

Woolly cupgrass [*Eriochloa villosa* (Thunb.) Kunth.] and common waterhemp (*Amaranthus rudis* Sauer) are relatively new and potentially serious weed problems in Iowa and surrounding states. Woolly cupgrass populations have increased rapidly in the last decade (Owen 1990) and their distribution has become widespread. This annual grass weed demonstrates biological, biochemical, and morphological characteristics that make it economically damaging and that add to the difficulty in developing effective management strategies. Common waterhemp populations have increased in Iowa with alarming speed and this weed appears to be extremely well adapted to current agricultural production systems. This paper discusses research conducted at Iowa State University on the factors influencing the severity of these weeds in Iowa agriculture and describes management strategies recommended for control.

Woolly Cupgrass

Woolly cupgrass was first reported in the United States by Hitchock (1950) and since then it has spread rapidly throughout the Midwest. Pohl (1959) first collected woolly cupgrass in 1957 from one county in southwestern Iowa and it is currently distributed throughout most Iowa counties. The spread has increased rapidly in the last 10 to 15 yr woolly cupgrass is currently estimated by the author to infest >20% of Iowa cropland. There are a number of reasons for this recent increased rate of distribution.

Woolly cupgrass has no special adaptations for seed distribution. Thus, gravity, water, soil movement, or animals were the primary distributors of woolly cupgrass seed. Recent changes in production agriculture, however, have strongly influenced weed seed distribution. These changes reflect differences in herbicide use, improved conservation practices, but more importantly, socioeconomic changes. Socioeconomic trends have resulted in fewer growers farming more land over greater distances and thus have influenced the spread of weeds more than any other factor of modern agriculture.

Farms that are located far apart can result in the accidental transport of weed seeds with equipment, particularly combines. Because farmers must use greater land resources to be economically successful, there are greater demands on the time available for weed management considerations. Scouting, sanitation, timely application of herbicides and increased use of custom herbicide application and harvesting all favor the spread of weeds into new areas. These factors have been particularly favorable for woolly cupgrass, a weed that has several biological, biochemical, and morphological adaptations that improve the competitiveness in agroecosystems.

Biological Adaptations of Woolly Cupgrass

Woolly cupgrass is a prolific seed producer. Estimates of seed productivity vary considerably but Bello (1988) reported that a single woolly cupgrass plant grown in a noncompetitive environment could produce >160,000 seeds. Importantly, woolly cupgrass seeds demonstrate near 100% viability consistently and are innately dormant at physiological maturity (Bello et al. 1998). Innate dormancy improves the potential for woolly

cupgrass to spread and increase in population size. Woolly cupgrass seeds have a strong stratification requirement (exposure to cold temperature) before dormancy is released. The implications of innate dormancy and the stratification requirement are the improved probability that woolly cupgrass seeds will not germinate when conditions do not favor the success of the seedlings.

In the field, the stratification requirement is met early in the winter thus making the seeds ready to germinate the next spring. The woolly cupgrass seed coat controls oxygen availability to the embryo and thus inhibits germination and serves as the basis for dormancy (Hatterman-Valenti et al. 1996). The cold temperatures break down the seed coat and the oxygen requirement is met.

Woolly cupgrass tends to germinate earlier and at larger populations than other annual grass weeds (Hartzler 1996a, d; Hartzler and Buhler 1997). Woolly cupgrass germinates several weeks earlier than giant foxtail (*Setaria faberi* L. Herrm) and exhibits a narrow emergence period (Hartzler 1996d) (Figure 1). Woolly cupgrass also germinates later in the season and has been observed to have as many as 8 germination cohorts during 1 growing season (Owen 1990). Recent data by Liu (unpublished) supports the importance of the first, early-germination cohort but also indicates that multiple germination events contribute to the management difficulties of woolly cupgrass.

Bello (1988) reported that woolly cupgrass could successfully germinate in a temperature range of 50° F to 104° F and successfully emerge at the soil surface or as deep as 4 in. Franzenburg (1994) suggested that there was a strong genetic component to woolly cupgrass adaptability and that genotypic characteristics that influence dormancy and germination are conserved. Thus, biological flexibility makes woolly cupgrass extremely well adapted to succeed in the conservation tillage systems that dominate current agriculture.

Importantly, the deeper-emerging and later-germinating woolly cupgrass seedlings are more likely to escape herbicidal control. Deeper-germinating seedlings will contact less herbicide due to concentration gradients from the soil surface to lower soil depths. Herbicides degrade over the growing season, thus, there will be less herbicide available to control later-germinating woolly cupgrass cohorts.

Woolly cupgrass is also very competitive compared with giant foxtail (Pecinovsky 1994). When woolly cupgrass and giant foxtail were grown together in pots at equal population densities, woolly cupgrass typically contributed 66% of the pot biomass suggesting that it is approximately twice as competitive as giant foxtail (Pecinovsky 1994). Owen (unpublished data) observed corn (*Zea mays* L.) yield reductions of 50 to 80% from season-long competition of woolly cupgrass. Tapia et al. (1997) reported a 33% average loss of corn yield attributable to giant foxtail, whereas woolly cupgrass caused an average loss of 41%.

Biochemical Adaptations of Woolly Cupgrass

There are numerous observations that woolly cupgrass is inherently more difficult to control with herbicides than many other annual grass weeds (Harvey 1974; Schuh and Harvey 1990, 1991; Owen et al. 1993; Pecinovsky 1994). Although biological adaptability is important, woolly cupgrass has demonstrated tolerance to most herbicides commonly used for control of annual grasses in corn and soybeans [*Glycine max* (L.) Merrill] (Pecinovsky 1994). Owen et al. (1993) observed that acetochlor (Harness, Surpass), alachlor (Lasso), and metolachlor (Dual) would not consistently provide 85% of woolly cupgrass even when applied at twice the labeled rate. This research was conducted over a 5-yr period and included growing seasons that were exceptionally wet and those that were dryer than average.

Pecinovsky (1994) compared the relative sensitivities of woolly cupgrass and giant foxtail to several herbicides and found that woolly cupgrass typically required twice as much herbicide as giant foxtail to reduce growth by 50%. These experiments were designed to minimize

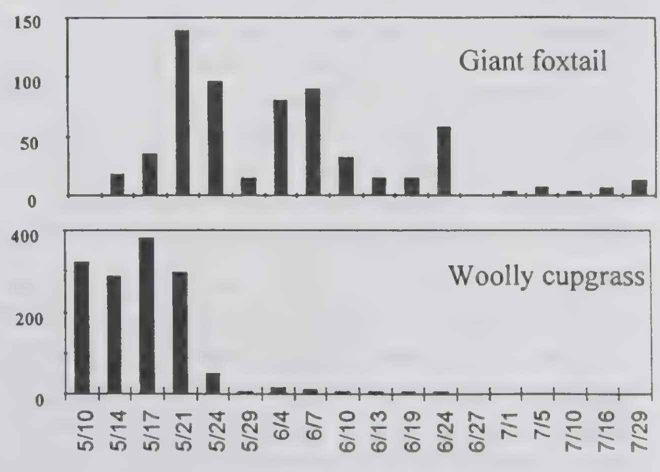

Figure 1 • Emergence patterns of giant foxtail and woolly cupgrass (1996). Hartzler and Buhler, Iowa State University and USDA–ARS. (Unpublished data.)

biological adaptations that might provide woolly cupgrass with greater tolerance to herbicides compared with giant foxtail. The differences observed were attributed primarily to greater differential metabolism of the herbicides by the woolly cupgrass; however, direct evidence of herbicide metabolism was not generated.

The primary means by which differential herbicide response occurs in plants is by metabolism of the herbicide to nonphytotoxic metabolites, differential uptake, or translocation (Brown et al. 1990). Hinz and Owen (1996) demonstrated that differences in response to nicosulfuron (Accent) and primisulfuron (Beacon) by woolly cupgrass were not attributable to differential uptake or translocation. Woolly cupgrass and corn had a similar half-life for primisulfuron of <4 h, whereas the half-life for nicosulfuron in woolly cupgrass was >72 h. Woolly cupgrass is sensitive to nicosulfuron and tolerant to primisulfuron. Further research demonstrated that woolly cupgrass metabolized primisulfuron but not nicosulfuron (Hinz et al. 1997).

Morphological Adaptations of Woolly Cupgrass

Woolly cupgrass can tiller rapidly and profusely (Bello 1988, Pecinovsky 1994). This ability was considerably greater than that of giant foxtail and was suggested to be a primary feature in the competitive ability of woolly cupgrass. Recent unpublished research by Liu, however, suggested that tillering had a significant impact on the herbicide response demonstrated by woolly cupgrass. This research expanded upon observations that woolly cupgrass survived nicosulfuron applications by initiating new tillers Pullins (1995). Liu (unpublished data) demonstrated that there was a vascular connection between the main stem and all tillers and that nicosulfuron would translocate from the main stem to all tiller buds. He speculated that tiller reinitiation resulted in poor control of woolly cupgrass even when observations suggested that the main stem was killed by the herbicide. The exact mechanism by which tillers were able to tolerate the herbicide was not described.

The ability of woolly cupgrass to germinate and emerge from deep in the soil is attributable to the mesocotyl elongation. Liu (unpublished data) observed that woolly cupgrass germination was deeper when preemergence herbicides were applied compared with the untreated control. He suggested that some of the tolerance demonstrated by woolly cupgrass was due to this morphological characteristic.

Management of Woolly Cupgrass

Although herbicides are the primary strategy used for woolly cupgrass management, they will not provide economically acceptable control consistently. Furthermore, given the current weed control expectations of growers, which are not a function of crop production economics or weed biology and, according to Hartzler and Owen (1997), totally unrealistic, there is little likelihood that a single herbicide application will eliminate a woolly cupgrass problem. Thus, when developing a woolly cupgrass management program, all tools should be considered and used as appropriate. Importantly, the management program must be developed to accommodate the crop agroecosystem and biological characteristics of woolly cupgrass. With effective management, woolly cupgrass can be eliminated from a field within 3 yr (Liu, unpublished data). To accomplish this goal, however, seed production and importation in the field must be eliminated. A more realistic goal is to maintain or diminish the seedbank and eliminate yield losses attributable to woolly cupgrass competition, which requires an integrated program using tillage, crop rotation, sanitation, mechanical tactics, and herbicides (Owen 1990, Hartzler 1996a).

Tillage

Although woolly cupgrass will be a serious problem regardless of the tillage system, reduced tillage practices tend to favor this weed over more aggressive tillage systems. Tillage practice directly influences the vertical and horizontal distribution of the seedbank. Tillage will spread a woolly cupgrass patch through a field, but the impact is considerably less than that of harvesting equipment. The vertical distribution dramatically affects the active woolly cupgrass seedbank. The deeper the tillage, the more diluted the seedbank becomes and the lower the seed population in the active zone. Liu (unpublished data) demonstrated that tillage lessened the woolly cupgrass seedbank compared with a no-tillage system and also caused seedlings to germinate deeper.

Importantly, tillage can be timed to effectively destroy the initial germination cohort without a loss of potential yield for corn and soybeans. Further, soil-applied herbicides tend to have more consistent efficacy when applied to a production system with lower amounts of plant residue on the surface. Finally, aggressive tillage can provide an "even start" for the crop and woolly

cupgrass (Hartzler 1996a; Staniforth, personal communication). Weeds tend to germinate more uniformly in time and in soil depth with tillage compared with no-tillage, and thus subsequent management strategies can be timed more accurately and are probably more effective. It is important, however, to balance the benefits of tillage on woolly cupgrass management with the risks of soil erosion.

Crop Rotation

Simple crop rotation systems create selection pressure that results in the weeds that are best adapted to that agroecosystem becoming the predominate species. Woolly cupgrass is most difficult to manage in a continuous corn rotation (Owen 1990). If soybeans are included in the crop rotation, there are several opportunities to improve woolly cupgrass management, including effective herbicides and delayed planting that favor better control of the initial germination cohort.

A better use of the management opportunities provided by crop rotation would be to include a forage crop such as alfalfa (*Medicago sativa*). Alfalfa production will allow herbicides to effectively control woolly cupgrass, mowing to eliminate seed production, dense stands to effectively compete with woolly cupgrass seedlings, and the woolly cupgrass seedbank to be significantly reduced after several years of alfalfa production. Because the woolly cupgrass seedbank in many fields is extremely large, however, sufficient seeds will germinate to replenish the seedbank if effective management is not implemented when the fields are returned to row crop production.

Sanitation

The best woolly cupgrass management program never allows a woolly cupgrass infestation to begin (Hartzler 1996a). Most new weed infestations occur because weed seeds are introduced to the field via equipment. If you have fields that are infested with woolly cupgrass, effectively isolate these fields and arrange the tillage and harvesting schedules so these fields are entered after all other fields have been completed. New weed infestations are found near entrances to fields, along fencerows, in terraces and in waterways. Scout these areas and remove any new weeds to keep them from spreading throughout the field.

Mechanical Tactics

If mechanical weed management tactics are not used, the potential to effectively control woolly cupgrass is greatly diminished. Without the use of rotary hoeing and cultivation, most of the control occurs with the herbicide. Rotary hoes provide an early opportunity to remove woolly cupgrass seedlings from a field. Rotary hoeing is effective, economical, and requires little time input. The use of a rotary hoe also will improve the opportunities for postemergence herbicide application timing, relative to the crop, by eliminating an early

Table 1 • Effect of grass size and Accent rate on giant foxtail control and corn yields.

Treatment	Rate (oz/acre)	Grass height (inches)	Giant foxtail[1] (% control)	Corn yield[1] (bu/acre)
Untreated	–	–	0E	123E
Preemergence	–	–	78D	167C
Accent	0.7	1–2	77D	171BC
Accent + cultivation	0.7	1–2	93AB	184A
Accent	0.7	2–4	88C	177AB
Accent + cultivation	0.7	2–4	95A	171BC
Accent	0.9	4–6	90BC	168BC
Accent	1.3	6–12	90BC	156D

Data are means of 9 experiments conducted in 5 states during 1992 and 1993 (Source: Tapia et al. [1997]).

[1] Means within columns followed by the same letter are not different at P<0.05.

Table 2 • Effect of grass size and Accent rate on woolly cupgrass control and corn yields.

Treatment	Rate (oz/A)	Grass height (inches)	W. cupgrass[1] (% control)	Corn yield[1] (bu/acre)
Untreated	–	–	0E	63C
Preemergence	–	–	63D	105A
Accent	0.7	1–2	49D	99A
Accent + cultivation	0.7	1–2	77B	106A
Accent	0.7	2–4	87A	102A
Accent + cultivation	0.7	2–4	–	–
Accent	0.9	4–6	92A	107A
Accent	1.3	6–12	77B	78B

Data are means of 9 experiments conducted in 5 states during 1992 and 1993 (Source: Tapia et al. [1997]).

[1] Means within columns followed by the same letter are not different at P<0.05.

woolly cupgrass germination cohort. Newer rotary hoes are designed to work effectively in high-residue crop production systems and can be used in narrow row soybeans.

The low cost, effectiveness, and versatility of row cultivation make it a critically important strategy for woolly cupgrass management. Tapia et al. (1997) demonstrated the importance of row cultivation to corn yield and reported improved giant foxtail and woolly cupgrass control when nicosulfuron applications were supplemented with row cultivation (Tables 1 and 2). Row cultivation can be used effectively in all tillage systems but should be timed carefully and done shallow to minimize moving seeds to a soil depth where they can germinate.

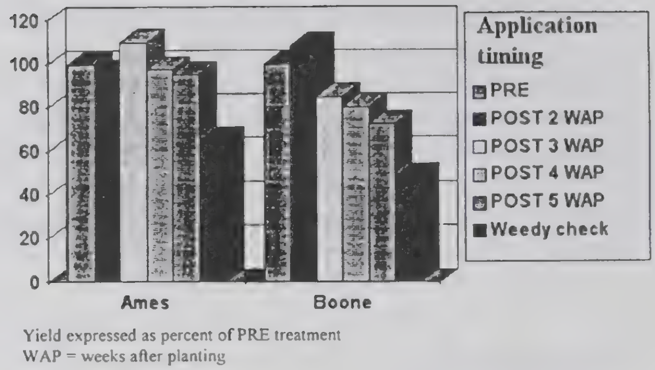

Figure 2 • Effect of postemergence timing on corn yield losses attributable to weed competition. (Owen et al. [1991]). Iowa State University. (Unpublished data.)

Herbicides

Although several herbicides are efficacious on woolly cupgrass, they will not consistently control this weed at levels to eliminate economic loss. As suggested previously, woolly cupgrass has many characteristics that lessen the effectiveness of herbicides, whether applied to the soil or postemergence. Historically, soil-applied herbicides have been used to manage woolly cupgrass and should be considered for an effective management system. Given the long germination period demonstrated by woolly cupgrass and the variable depth of emergence, soil-applied herbicides will not consistently provide acceptable control.

The chloroacetamide herbicides all have some activity on woolly cupgrass. Owen et al. (1993) reported little difference among the chloroacetamide herbicides evaluated for woolly cupgrass control. Importantly, there were no consistent differences between preplant incorporated and preemergence application techniques. The highest level of control was observed when these herbicides are applied preemergence, but performance was strongly correlated with rainfall. There are currently numerous chloroacetamide herbicides available and the author suggests that any of them, given the rates that are typically applied, will provide similar control of woolly cupgrass. The level of control, however, will not be sufficient to protect crop yields. Pendimethalin (Prowl) also demonstrates excellent but inconsistent control of woolly cupgrass. Research at Iowa State University demonstrated that pendimethalin very effectively provided residual woolly cupgrass control in corn when applied in combination with a postemergence herbicide such as nicosulfuron.

Isoxaflutole (Balance) has demonstrated consistent activity on woolly cupgrass but should be considered as a component of a management program. Supplemental strategies such as mechanical control or postemergence herbicide applications should used as appropriate.

Herbicide-resistant crops and the appropriate herbicide provide some opportunities to manage woolly cupgrass. Roundup Ready crops, Liberty Link crops, Imi corn, and SR corn all have utility in a woolly cupgrass management program. Glyphosate (Roundup Ultra), glufosinate (Liberty), imazapyr plus imazethapyr (Lightning), and sethoxydim (Poast Plus) all demonstrate excellent activity on woolly cupgrass. Like most postemergence herbicides, however, these products have little or no residual activity. Thus, proper herbicide application timing, multiple herbicide applications where appropriate, and alternative strategies are needed for a complete woolly cupgrass management program.

Nicosulfuron has been the primary herbicide used in corn for woolly cupgrass control. It has provided consistent control, but requires appropriate timing (Hartzler 1996b) (Figure 2). Given the level of activity that nicosulfuron has on woolly cupgrass and the concern for later germination events, commercial applications tend to be delayed. This delay can cause a reduction in yield potential due to weed interference. Although the prediction of when weed interference will begin to reduce corn yield is impossible, typically an application within 3 or 4 wk after corn emergence will protect yields.

The exact time that weeds begin to cause crop yield reductions, however, will be dependent upon environmental conditions and weed populations. Dense populations of woolly cupgrass and giant foxtail caused a significant yield reduction compared with a preemergence application of metolachlor when nicosulfuron

application was delayed 3 wk after planting (Figure 2). In Ames, where woolly cupgrass was not part of the weed flora and the giant foxtail population was lower, nicosulfuron application could be delayed until 5 wk after planting without a loss of yield. The problem with predicting the correct postemergence herbicide application timing reinforces the need for the initial use of a soil-applied herbicide or another strategy to minimize early woolly cupgrass populations.

There are a number of herbicides that can be used in soybeans that have excellent activity on woolly cupgrass, including soil-applied dinitroaniline herbicides such as trifluralin (Treflan) and pendimethalin. There are also a number of postemergence-applied herbicides for annual grass weed control. These postemergence herbicides include clethodim (Select), fluazifop-p-butyl (Fusilade DX), fluazifop-p-butyl plus fenoxaprop (Fusion), quizalofop-p-ethyl (Assure II), and sethoxydim (Poast Plus and Prestige). These products also may be included in commercially available prepackage tankmixes. None of these products has residual activity on woolly cupgrass and should be considered as a component of a woolly cupgrass management program in soybeans.

Woolly Cupgrass Management Summary

The adaptability of woolly cupgrass to circumvent single management strategies, whether the strategy is herbicidal, mechanical, or cultural, dictates that growers develop an integrated management program. Not all strategies will be needed every year. If alternative tactics are eliminated, however, without consideration of the risk their loss represents to an economically effective woolly cupgrass management program, woolly cupgrass management will be difficult at best.

Common Waterhemp

Common waterhemp is another relatively new weed problem in Iowa and the Midwest. Common waterhemp is a native species that has been identified by botanists in the historic taxonomic records. Interestingly, a survey conducted in the 1930s (anonymous) reported that waterhemps were not a major component of the weed flora in the southern half of Iowa. Currently, common waterhemp is a serious weed problem in this area and throughout Iowa. There have been changes in agricultural practices that have favored this weed (Owen, personal observation; Hartzler 1996c, Hartzler 1997). These changes include reductions in tillage, herbicide selection, simplified crop rotations, and recent weather patterns that have resulted in the relatively rapid rise in importance of common waterhemp to Iowa agriculture. Because waterhemp is a relatively new weed problem, limited research has been conducted on it. Most of the research has focused on the relationship of this weed complex with herbicides. Specifically, due to difficulties in controlling common waterhemp with herbicides that inhibit acetolactate synthase (ALS) activity, there have been numerous studies describing ALS resistance (e.g., Hinz and Owen 1997) but little biological research.

At Iowa State University, weed scientists have begun to focus on the biology, ecology, and biochemistry of common waterhemp (Hartzler 1996c, d; 1997; Hartzler and Buhler 1997; Pratt et al. 1997, 1998). Without an understanding of how common waterhemp populations develop, how the plant grows, the taxonomic characteristics of the waterhemps, and mechanisms of herbicide tolerance and resistance, it is not possible to develop effective management programs.

Common Waterhemp Taxonomy

Most current herbicide labels include pigweeds (*Amaranthus* spp.), common waterhemp, and tall waterhemp (*Amaranthus tuberculatus*). The efficacy data used to support these label recommendations, however, are often derived from field experimentation where the pigweed complex was incorrectly identified. Often these different *Amaranthus* spp. were grouped as one taxon, and resultant efficacy observations attributed to the wrong pigweed species.

Pratt (personal communication), Wax (personal communication) and Horak (personal communication) all suggest that identification of many pigweeds in the vegetative stage of growth is difficult at best, and impossible for the dioecious waterhemp complex. Given these problems, and the observed differences in growth habit, it is not surprising that growers have been frustrated with ìpigweedî control failures and agricultural chemical companies have changed label recommendations on many herbicides.

Weed scientists have generally suggested that redroot pigweed (*Amaranthus retroflexus*) is the dominant pigweed species in the Midwest; however, the author suggests that misidentification has been widespread and consistent. In reality, common waterhemp is probably the primary pigweed causing economic losses in Iowa agriculture. Observations indicate that common

waterhemp populations have increased dramatically over a 5-yr period. Understanding the changes that have occurred in agriculture that facilitated this shift would help to develop effective management strategies. An important first step is to identify exactly which pigweed is causing the problem.

Pratt et al. (1997) reports that common waterhemp and tall waterhemp are described as separate species; however, there is evidence that this commonly accepted "fact" is incorrect and understanding the genetic background will improve management. The taxonomic differences differentiating the waterhemps were minute pistillate floral characteristics. When the herbarium records were reviewed, Pratt et al. (1998) found a number of waterhemp intermediate forms from Iowa, Illinois and Missouri that made differentiation of waterhemps suspect. They suggested that evidence from 203 herbarium specimens do not adequately characterize common and tall waterhemps and that this complex is extremely diverse morphologically in the Midwest. As a result of this investigation, they proposed 2 hypotheses to account for the herbarium evidence: (1) there is a single waterhemp species (*Amaranthus rudis*) that has considerable morphological diversity centered in the Midwest; and (2) two waterhemp species exist, however hybridization occurs in the Midwest. Regardless of which hypothesis is correct, the implications of the morphological diversity demonstrated by the waterhemps is exceptional genetic flexibility that may result in adaptation to management strategies.

Common Waterhemp Biology

Hartzler and Buhler (1997) initiated an extensive weed emergence research project in 1995 begun because they recognized that current weed management strategies focused only on herbicide selection and were not providing the consistent control of weeds needed to ensure economic success for producers. They understood that information on weed emergence was critically important to improve the effectiveness of herbicides and to reduce the negative environmental impact of herbicides. A description of common waterhemp emergence patterns was a significant part of this research.

Hartzler (1996d) reported that common waterhemp emerged consistently late in the growing season (Figure 3). Compared with velvetleaf (*Abutilon theophrasti*), common waterhemp emergence in 1996 began ≈2 wk later and continued for 2 mo. Velvetleaf had a relatively short germination period of 3 wk. This pattern of late

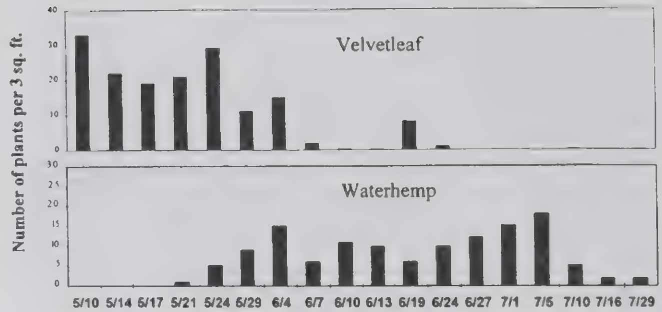

Figure 3 • Velvetleaf and waterhemp emergence patterns (1996, Ames, IA). Hartzler and Buhler, ISU, and USDA–ARS. (Unpublished data.)

and extended emergence has been consistent over several years (Hartzler, personal communication) and has important implications in management.

In many weeds, late emergence is not a major management issue because the crop canopy effectively competes with the weed. Common waterhemp, however, is able to emerge late and grow through the crop canopy (Owen, personal observation). The biological and morphological reasons to support this observation are not fully understood; however, research by Hartzler and Battles (unpublished data) demonstrates that the crop canopy does have a significant effect on common waterhemp survival and growth (Figure 4). Common waterhemp that emerged after crop planting demonstrated a lower survival rate, were shorter, and accumulated less biomass compared with plants that emerged with the crop. Some common waterhemp plants, however, were able to survive even when they emerged when soybeans had 6 trifoliates.

The success of later-emerging common waterhemps is dependent upon the environmental conditions (Hartzler and Battles, unpublished data) (Figure 5). In 1998, common waterhemp that emerged when soybeans had 6 trifoliates were able to emerge through the soybean canopy; however, in 1997, common waterhemp seedlings that emerged after soybeans had two trifoliates were not able to survive. Rainfall was abundant after soybean planting in 1998 but was limited in 1997.

Other biological characteristics that contribute to the rapid increase in common waterhemp populations are high seed production and an ability to germinate from shallow soil depths (Hartzler 1997). Small-seeded annual weeds such as common waterhemp must be near the soil surface to successfully germinate and emerge. Reduced and no tillage systems that have increased in the Midwest favor the establishment and success of common waterhemp populations.

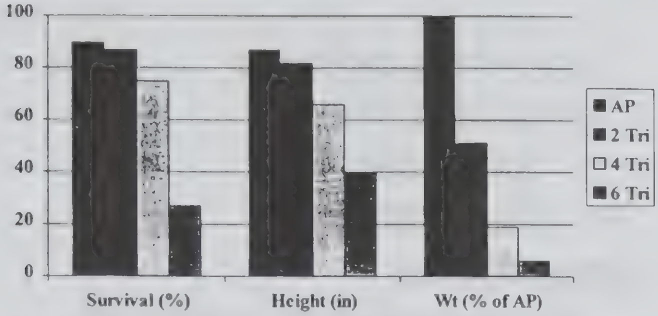

Figure 4 • Influence of emergence date on waterhemp survival and growth (Collins, IA). Hartzler and Battles, ISU, 1998. (Unpublished data.)

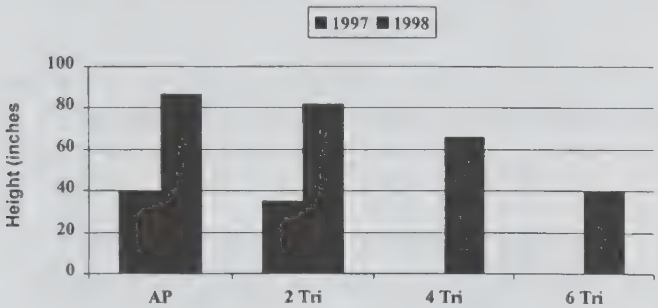

Figure 5 • Influence of weather on waterhemp in 1997 and 1998. Hartzler and Battles, ISU, 1998. (Unpublished data.)

Common Waterhemp Biochemistry

As previously indicated, there has been considerable research describing herbicide resistance in common waterhemp (Horak and Peterson 1995; Sprague et al. 1995; Hinz and Owen 1997). Given the genetic flexibility attributable to the dioecious growth habit, the widespread use of ALS-inhibiting herbicides, and the apparent plasticity of the ALS coding (Guttieri et al. 1992, Bernasconi et al. 1995, Siehl et al. 1995), the common appearance of ALS-resistant common waterhemp biotypes was anticipated. Hinz and Owen (1997) demonstrated that the ALS-resistant common waterhemp population demonstrated cross-resistance to imidazolinone and sulfonylurea herbicides. Similar results were reported by Horak and Peterson for palmer amaranth (*Amaranthus palmeri*).

Growers have reported considerable difficulty in controlling common waterhemp with other postemergence herbicides such as lactofen (Cobra) and aciflurofen (Blazer, Status). Hinz and Owen (1997) reported that the ALS-resistant common waterhemp biotype was sensitive to lactofen. The lack of control reported by growers was probably attributable to poor application timing or rate selection (Owen, personal observation).

Recently, there have been several locations where common waterhemp control from glyphosate was inconsistent and poor. Cursory evidence has demonstrated a differential response by these populations to glyphosate rates that control other populations of common waterhemp. Field inspection by the author has ruled out poor application technique and application timing. The grower used multiple applications of glyphosate at rates that should provide control of most annual broadleaf weeds. Research is underway to determine the specific mechanisms responsible for the poor efficacy on these common waterhemp populations.

Common Waterhemp Morphology

Observations by the author suggest that common waterhemp morphology may play a significant role in common waterhemp responses to postemergence herbicides; however, there have not been any definitive studies conducted to define this role. Common waterhemp appears to have the capability to grow rapidly and elongate stem length. This ability may have implications on herbicide translocation. Furthermore, given the overall size of common waterhemp plants, there appears to be relatively little leaf area. Herbicide coverage and uptake may be negatively affected by the lack of leaf area. Common waterhemp also has multiple meristems at each leaf axil and the base of each branch that could affect the effectiveness of herbicide coverage whether the herbicides are translocated or contact types.

Common Waterhemp Management

There are several problems that must be resolved to develop and effective common waterhemp management program. Generally, common waterhemp seedlings are sensitive to most soil-applied herbicides. Acetamide, triazine, and dinitroaniline herbicides are all effective; however, the delayed emergence of common waterhemp and applications of these herbicides early in the spring result in inconsistent control. The rates of soil-applied herbicides commonly used will not last until most of the common waterhemp emerges (Hartzler 1997). Like with other weeds, effective common waterhemp management programs are diverse and integrate several strategies.

There are a number of herbicides labeled for application to soybeans that have activity on common waterhemp. Sulfentrazone (Authority) demonstrates good activity but will not provide residual control long enough to effectively manage a common waterhemp infestation. Postemergence applications of diphenyl ether herbicides are also effective. These products include aciflurofen, fomesafen (Flexstar, Reflex), and lactofen; however, these products are often applied when common waterhemp is too large for consistent control. Applications should be made when common waterhemp is <4 in. in height. Similarly, glyphosate and glufosinate provide the best control when applied to small, actively growing common waterhemp. Pendimethalin and trifluralin have excellent common waterhemp activity. Flumiclorac (Resource) also demonstrates some common waterhemp control.

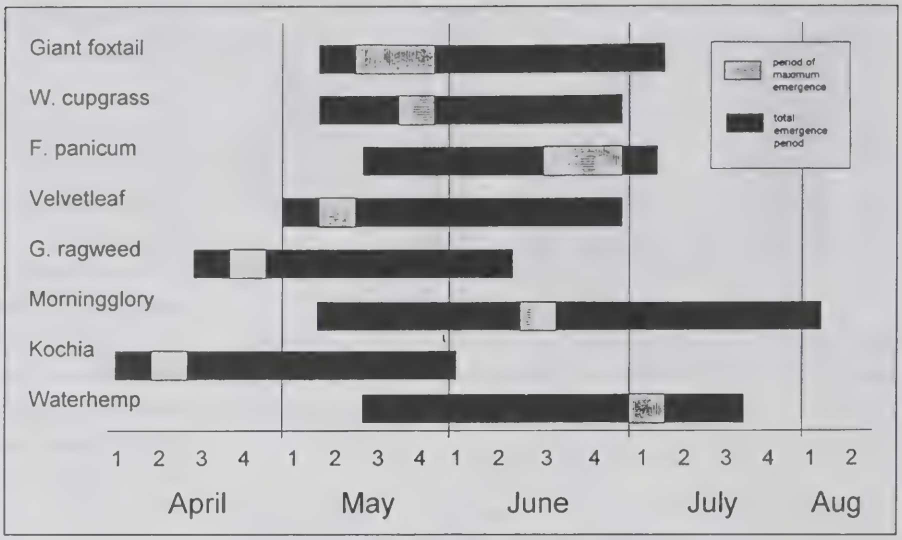

Figure 6 • Weed emergence patterns. Hartzler and Buhler, ISU, and USDA–ARS, 1997.

In corn, atrazine provides exceptional control of common waterhemp. Dicamba (Banvel, Clarity) and 2,4-D (various) have good postemergence activity on common waterhemp. Any premixture containing atrazine (e.g., Marksman) also will control common waterhemp; however, the atrazine restrictions minimize the effectiveness of these treatments for late-emerging populations. Corn hybrids that are resistant to glyphosate or glufosinate also represent a management option.

Generally, however, effective control of common waterhemp will not be achieved with herbicides. The ALS herbicides have not provided control of this weed even though resistance to these herbicides is not thought to be a widespread problem. The best alternative strategy is row cultivation just prior to crop canopy closure. Late common waterhemp plants are not particularly competitive but will still manage to grow above the canopy. A lay-by cultivation will control these plants consistently and economically.

Common Waterhemp Management Summary

The rapid increase in common waterhemp populations is an excellent example of the weed community adapting to fill available ecological niches (Hartzler 1997). The author suggests that the late and extended germination characteristic is the result of the selection pressure from extensive atrazine use in corn and dinitroanilines in soybeans. These herbicides removed individuals from the population with the genetic characteristic to germinate early and favored the late-emerging genotype (Hartzler and Buhler 1997) (Figure 6). Evidence exists that germination habit is a conserved genetic trait (Franzenburg 1994). Furthermore, increased use of conservation tillage favors a weed such as common waterhemp. The widespread use of ALS-inhibiting herbicides also has effectively removed other weeds from the fields, thus opening a niche for common waterhemp, which demonstrated resistance to this mechanism of herbicide action. Without a diverse management program, common waterhemp will rapidly become a serious weed problem in fields throughout the Midwest.

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GENETIC VARIABILITY IN WEED POPULATIONS

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When making your weed management decisions, do you expect that your grass and broadleaf weeds will respond in the same way to particular treatments? Of course not. In fact, you recognize that even within these general weed classes different species respond differently. The herbicide Classic® does a great job in managing common cocklebur, for example, but not on prickly sida. Common cocklebur is a strong competitor with soybean [*Glycine max* (L.) Merrill]; prickly sida is a weak competitor. You are aware of these types of differences among the weed species in your fields and you factor these differences into your weed management decisions. But are you aware of differences among individual weeds within the same species? Do you factor these differences into your weed management decisions? Should you?

Just as individual people differ in, for example, how tall they grow, how strong they are, and how much alcohol they can tolerate, individuals of a particular weed species differ in how tall they grow, their level of competitiveness, and how much herbicide they can tolerate. The distinct environmental conditions experienced by individuals account for some of these differences, but other differences are due to innate (genetic) variability among individuals. Genetic variability within a species results from mutations, polyploidy, shuffling of genes during sexual reproduction, and cross-species hybridization.

The most apparent examples of genetic differences among individuals of a particular weed species are herbicide-resistant biotypes. In several weed species, due to a single genetic difference, some individuals are not affected by application of the normal use rate of a particular herbicide, whereas other individuals of the same species are effectively controlled by such a treatment. In Illinois, this type of intraspecific genetic variability is exemplified by biotypes of waterhemp, kochia, common lambsquarters, and common cocklebur that are resistant to triazine, ALS-inhibiting herbicides or a combination of herbicides. These weeds exhibit dramatic differences in herbicide response; however, genetic differences within a species are not limited to those that have dramatic effects. Although the effects of these differences may not be dramatic, they may still be important to weed management.

When a single gene change confers a dramatic change in the phenotype (i.e., observable characteristics) of an individual, such as when a single mutation in a weed confers a 100-fold level of herbicide resistance, that trait is said to be a qualitative trait. Quantitative traits, in contrast, are controlled by several genes. Any one gene usually influences quantitative traits, such as growth rate and competitive ability, only slightly. Because the effects of many genes are manifested only in quantitative traits, a few genetic differences often result in little or no phenotypic differences. The right combination of several quantitative genes, however, can result in important phenotypic differences.

Examples of Variability Within Weed Species

Results of several studies have indicated that at least some weed species contain sufficient genetic variability such that individuals of those species vary in their weediness characteristics. Several years ago, johnsongrass ecotypes were shown to display a range in morphological and growth characteristics (McWhorter 1971). A nearly twofold range in plant heights, leaf

lengths, and leaf widths was observed among individuals collected from different geographical regions. One would expect that differences in plant heights would affect competitive ability, whereas differences in leaf widths may affect herbicide retention and efficacy. Genetic variability within field pennycress may control whether some individuals respond as summer annuals or as winter annuals (Best and McIntyre 1972). Whether weeds germinate in the spring and set seed in the fall, or germinate in the fall and set seed the following spring affects a weed management approach.

More recently, analysis of hemp dogbane ecotypes collected in Illinois and Michigan revealed that individuals may vary substantially in several growth parameters (Ransom et al. 1998b). One hemp dogbane individual produced 9 times more shoots and covered 19 times more area than another individual. The more aggressive ecotype would be expected to show greater yield reductions when grown with a crop. A follow-up study, which used molecular biology techniques, provided evidence that these phenotypic differences were due to genetic differences that exist within the hemp dogbane species (Ransom et al. 1998a). The use of molecular biology to study genetic variation of weeds at the DNA level rather than at the phenotypic level eventually should provide insight into how weed management practices influence the genetic makeup of weeds and what traits are controlled by certain genes. In addition to hemp dogbane, the following weed species have been the subjects of diversity analysis at the DNA level: yellow nutsedge, purple nutsedge, leafy spurge and wild mustard (Moodie et al. 1997; Rowe et al. 1997, Abad et al. 1998, Wills 1998).

As mentioned, pronounced differences in herbicide sensitivity among biotypes of a weed species are well documented. Less well documented are the more subtle differences in herbicide sensitivity among individuals of a particular weed species. A comparison of common cocklebur ecotypes revealed a small but significant difference in sensitivity to bentazon (Anderson 1982). The observed difference in herbicide sensitivity might be due to a quantitative rather than to a qualitative genetic trait. For example, several genes may control leaf cuticle thickness, transpiration rates, and metabolic rates, all of which could have minor effects on herbicide sensitivity. Studies have shown that common cocklebur is a highly variable species. Early taxonomic literature suggests that common cocklebur actually can be subdivided into a dozen or more different species (Fernald 1970). Given such diversity within common cocklebur, it is reasonable to assume that variability in sensitivity to other herbicides as well as in morphological and growth traits exists among individuals of this species. Recently, I began characterizing common cocklebur ecotypes collected from across the United States. Preliminary data indicate that some individuals have up to 40% higher photosynthetic rates than other individuals.

Collectively, the studies that I have summarized herein indicate that within a weed species, differences exist among individuals. These differences are often observed only among individuals collected across broad geographical regions. Do differences among individuals of a species also exist at local levels?

Common waterhemp and tall waterhemp (collectively referred to as waterhemp) have spread rapidly throughout much of Illinois during the last few years. Several attributes of waterhemp make it a difficult weed to manage. One attribute is its highly variable nature. Even within a single field, one can often observe differences in plant pigmentation, leaf shape, and branching frequency. Many of these differences probably are due to genetic differences among individuals. These genetic differences also probably influence such traits as competitive ability, seed dormancy, and herbicide sensitivity that, in turn, affect weed management. One reason why waterhemp may exhibit such variability is that it can cross-hybridize among species. Common and tall waterhemp probably can hybridize with each other, and both of these species may be able to hybridize with Palmer amaranth. All 3 of these species are dioecious (i.e., there are separate male and female plants), thus ensuring that gene mixing during sexual reproduction occurs, further enhancing the potential for variability among individuals. Although environmental factors probably play a more important role, genetic variability also may play a role in the inconsistent waterhemp control observed with various herbicides.

Impacts on Weed Management

So how should we incorporate into our weed management approaches our knowledge of genetic variability within weed species? First, it is important to recognize that just because 2 plants belong to the same species, they may not be identical. The common cocklebur plants used in a weed-crop competition study in Iowa may be different from the common cocklebur plants that exist in a field in Illinois. Second, we need to be aware that all individuals of a particular species may not respond identically to a particular treatment. Subtle differences in herbicide sensitivity may not be apparent under most conditions, but if conditions for herbicide

efficacy are less than ideal, individual plants with slightly less sensitivity than the majority of the population may survive. Similarly, individuals possessing slightly greater seed dormancy may emerge later in the season, thereby avoiding a postemergence herbicide application. The genetic traits controlling these subtle differences will be selected for in a similar way that a qualitative trait (such as a 100-fold level in herbicide resistance) is selected. Thus, over time, our management practices may select for quantitative traits, making weeds more difficult to control.

Unfortunately, we do not have detailed information describing the extent of genetic variability within most of our weed species, nor do we have detailed information on what traits are affected by the genetic variation. As weed management becomes more and more sophisticated, however, recognition and documentation of genetic variability within the species we are trying to manage must be taken into account. In the next several years, expect to see more research into the genetic variability of weed species.

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CONTROL OF AQUATIC WEEDS IN LAKES AND PONDS

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Aquatic plants are natural and important components of the aquatic environment. Microscopic plants (algae) form the base of the aquatic food chain. Larger algae and plants provide habitat and shelter for fish, waterfowl, and other wildlife; and all plants produce oxygen as they photosynthesize during the daylight hours. Because of these benefits, some aquatic plant growth in a body of water is desirable. Excessive growth of aquatic plants, however, can have detrimental effects on a body of water, its inhabitants, and its users. Some of the problems caused by excessive aquatic plant growth are as follows:

1. Recreational activities such as swimming, fishing, and boating can be impaired and even prevented.
2. Excessive plant growth can lead to fish stunting and overpopulation because the production of too much habitat prevents effective predation of small fish by larger fish.
3. Aquatic plant and algal growth can play a role in causing fish kills because oxygen is taken out of the water. During the day, plants produce oxygen through photosynthesis; at night (as well as during the day), they consume oxygen through respiration. If plant growth is excessive, plants at night can consume most of the oxygen in the water. Fish that are stressed for oxygen often die just before dawn when the oxygen content in the water is lowest.

Oxygen depletion also occurs when plants die and decompose. When plants die, photosynthetic production of oxygen ceases, and the bacteria, which break down the decaying plant material, consume the oxygen in their own respiration.

Fish kills can occur in the summer or in the winter. Summer fish kills can be caused by die-offs and decomposition of algal blooms. Even if fish are not directly killed by algal die-offs, any sort of stress, such as excessive plant respiration at night or prolonged periods of cloudy, warm days that cause a reduction in photosynthesis and oxygen production, can lead to greater fish susceptibility to diseases and toxicants.

Fish kills in winter occur when snow accumulates on ice cover. Light is blocked, thus preventing photosynthesis by any living plants or algae. Decomposition of plants that died in the fall causes further oxygen depletion. Other causes of fish kills include insecticide runoff, ammonia runoff from feedlots or leakage from storage tanks, and diseases.

4. Aquatic weed growth provides stagnant water areas ideal for mosquito breeding.
5. Certain algae can impart foul tastes and odors to water.
6. Weeds impede water flow in drainage ditches, irrigation canals, and culverts and cause water to back up.
7. Deposition of weeds, as well as sediment and debris, can cause the gradual filling in of bodies of water.
8. Excessive weed growth can lower property values and decrease aesthetic appeal of a body of water.
9. Exotic aquatic plant species (e.g., Eurasian watermilfoil, purple loosestrife) can invade and completely take over stands of native vegetation. This process upsets the natural balance in an aquatic system and can have adverse effects on the animals that depend on the native vegetation for habitat and food.

The goal for a person managing a body of water is to achieve a balance: some vegetation is desirable and can

add interest and appeal. A sterile, swimming-pool effect for a natural body of water should be avoided. How do we achieve this balance? We attempt to do it by careful use of one or several management method; including preventive, mechanical, biological, habitat alteration, and chemical methods.

Preventive Control Methods

Many aquatic weeds or their seeds are carried into a body of water by wind, birds, fish introduction, fishing, etc. These weeds become infestations only if the water conditions are just right, for example, if the body of water is shallow or has shallow areas with good light penetration and has an available source of nutrients (nitrogen and phosphorus), either in the water or stored in the sediment. Often nutrients enter a body of water from runoff or stream flow. Nutrient inputs can be reduced by initiating a good management plan for the watershed (the area that drains into the body of water). In addition to surveying the watershed and reducing or eliminating nutrient or sediment sources, the following protective measures should be considered:

1. Do not fertilize the pond or lake. Most midwestern waters are sufficiently rich in plankton and other food organisms to support large fish without being fertilized.
2. Maintain a good sod and grass cover around the body of water to help prevent runoff and erosion. Lawn fertilizers should not be applied any closer than 10–20 ft from the shoreline. Greenbelts should be established along waterways draining into the pond or lake.
3. Do not allow livestock access to a pond except under conditions of extreme heat stress. If the water is used for livestock, fence the pond. Water the animals from a stock tank below and outside the fence. Animals in the water will increase turbidity and fertility and tear down the banks.
4. Check septic tanks for possible leakage or seepage into the water. New septic drainage fields should be directed away from the body of water.
5. Do not permit runoff from chicken coops, feedlots, etc., to enter the body of water. If this kind of runoff is occurring upstream from the water site, check with the county board of health to see if anything can be done about it.
6. Establish a settling or retention pond or wetland area to receive nutrients before the flow reaches the main body of water.
7. Do not spread aquatic vegetation. Remove vegetation from boat trailers, boat wells, and bait boxes before moving them to another body of water.

All of these measures will help prevent weed growth, particularly in a newly constructed body of water. In older bodies of water, these measures will aid in gradually reducing infestations of free-floating plants such as microscopic algae and duckweed.

Mechanical Control Methods

Even with preventive measures, many bodies of water still have severe plant infestations. Hand-pulling or raking plants is a possible method of control. Because most aquatic plants are perennial with underground portions that can resprout new shoots, it is essential that belowground growth also be harvested. For larger plants such as cattails, removing growth is difficult. Hand-held devices for cutting or pulling plants in small areas are available from dealers that specialize in aquatic and fisheries supplies.

For larger bodies of water, motor-driven underwater weed harvesters are available. This equipment is usually a major investment and may have to be operated several times during the season to effectively keep the vegetation cut back. The premise is the same as mowing a lawn. The weeds are not eliminated but they can be prevented from becoming a nuisance. The cut vegetation should be harvested and dumped where it cannot reenter the water. Plant fragments, even less than an inch in length, left to float in the water can produce a new plant. The harvested material can be satisfactorily used as a fertilizer or mulch in gardens or as land fill. Some states require permits for harvesting on natural lakes; check with your state regulatory agencies to determine if such permits are required.

For more information on weed-harvesting equipment, write to the following companies (only 2 of several companies; their listing does not imply an endorsement of their products):

United Marine International LLC
P.O. Box 25
Syracuse, NY 13215
Phone 315-487-2577, fax 315-487-2451

Aquarius Systems
200 N. Harrison
P.O. Box 215
North Prairie, WI 53153
Phone 414-392-2162

Biological Control Methods

Biological controls (i.e., organisms that control pest organisms) have received considerable publicity. Bacteria, fungi, and insects currently are being tested for their ability to reduce aquatic plant infestations. Certain insects appear to have potential for the control of Eurasian watermilfoil and purple loosestrife. Waterfowl such as swans can keep small ponds weedfree, but they require some husbandry and protection from predators. They also are extremely aggressive during and following the breeding season.

The most widely used biological control agent to date is a herbivorous fish, the grass carp (also known as the white amur). This fish is not legal in all states. Check with the appropriate state regulatory agency or fish and game agency to determine if the fish is legal in your state, and for permit information and restrictions if it is legal.

The grass carp is native to China and Russia. It can live 15–20 yr. This fish consumes some filamentous algae and most submersed plants. Because it has the potential to denude a body of water of its underwater vegetation, it must not be released in natural lakes and wetland areas where vegetation is critical to fish and wildlife. For example, in Indiana the land surrounding a pond or lake must be totally in private ownership and all precautions must be taken to prevent escape of the fish from the stocked area. Barriers should be erected at the spillway or outflows.

The type of grass carp that is most commonly legal in the North Central Region of the United States is the triploid grass carp, a form that will not reproduce itself. Regulations vary regarding stocking. In Indiana, for example, fish must be purchased from a holder of an aquaculture permit. The permit holder must deliver and stock the fish and present the purchaser with a bill of sale and copy of triploid certification. It is the responsibility of the purchaser to retain these documents for at least 2 yr.

Typical stocking rates are 15 or 30 fish per acre. Fish should be 8–12 in. in length. Smaller fish will be rapidly removed by predators such as bass. The lower stocking rate is recommended for most ponds so that some vegetation remains. Where total vegetation control is desired (e.g., in ponds on golf courses), the higher stocking rate can be used. Vegetation control may not be observed for a year or more; after about 5 yr, the grass carp slows its feeding rate so that more fish may be needed to maintain adequate vegetation control.

Although the grass carp has provided good control of aquatic vegetation in some situations, it is not the solution for all ponds. Because its effects on vegetation may not be noticed for a year or more, it may be difficult to determine if enough fish are still present in the pond to be effective. In addition, the grass carp prefers certain plant species over others. For example, it consumes native species such as pondweeds before it feeds on truly troublesome weeds such as Eurasian watermilfoil or filamentous algae.

Habitat Alteration Methods

Certain methods of manipulating or altering the aquatic environment can be effective in aquatic plant management. One of the more successful methods is the drawdown technique in which water levels are lowered over the winter. Exposure of the sediments in the shallow areas of a lake or pond to alternate freezing and thawing action will kill the underground structures of many aquatic plants. This method has been successful for the control of Eurasian watermilfoil and waterlilies, although the degree of control depends somewhat on the severity of the winter.

Other types of habitat manipulation include riprapping shorelines or anchoring black plastic sheeting on the bottom sediments to prevent rooted plant growth. Dyes such as Aquashadow® are used to inhibit light penetration throughout the water. This blue dye can be applied right out of the bottle along the shoreline. It mixes throughout the body of water within 24 h. The dye intercepts light normally used for photosynthesis by underwater plants. The dye can only be effective if its concentration is maintained. Some general rules for using Aquashadow® or other dye products are as follows:

1. Do not apply where water outflow will reduce the dye concentration.
2. Apply in March or April before plants reach the water surface. Midsummer reapplication is usually necessary. Dyes are effective only on rooted underwater plants growing at depths greater than 2 or 3 ft. Supplemental treatments of copper sulfate might be needed for algae control.
3. Do not use in muddy water.

Aeration has been publicized as another method of weed control. Although aeration is definitely beneficial for fish life and can help prevent fish kills, there is no evidence that aeration inhibits weed growth.

Chemical Control Methods

When properly applied, certain herbicides can control aquatic vegetation without harming the fish and other wildlife. In some instances, herbicides can be used selectively, that is, to control certain plant species without killing others. Aquatic herbicides also can fit into an aquatic plant management plan when it is desirable to treat some vegetated areas and leave others untreated. They can be particularly effective for controlling certain aggressive weed species such as Eurasian watermilfoil.

It should be noted that, in most cases, aquatic herbicides offer only temporary solutions. The target species usually reappear, and retreatment or application of another control method usually is necessary.

All of the herbicides discussed in this paper are registered with the federal Environmental Protection Agency (EPA) and, when used in water as directed, generally pose no significant threat to the environment or to public health. Most herbicides, however, are toxic if taken internally, and direct contact with the chemical should be avoided. Protective clothing, gloves, and a face mask or respirator should be worn during mixing and application. If a herbicide comes in contact with the skin, it should be washed off immediately with water. If a herbicide is accidentally swallowed, go to a physician immediately and consult the container label for first aid information.

Because these chemicals are toxins and require special precautions, the remainder of this paper is devoted to the proper use of aquatic herbicides. Check with the appropriate state regulatory agency for a list of the herbicides approved for use in your state, and for other restrictions and important information.

What You Need to Know Before Using a Chemical

Before buying and applying a herbicide it is essential to read the label to determine whether the product will meet your needs. Important considerations in choosing a herbicide include the following:

1. **Identity of the weed.** Proper weed identification can save you a lot of money because certain chemicals will work only on certain weeds and not on others. Help with identification can be obtained from your county or university Cooperative Extension Service, pest diagnostic services, fisheries biologists, or dealers of aquatic herbicides. Always transport or mail the plant in a plastic bag without extra water.
2. **Restrictions on use of water treated with herbicides.** Although most aquatic herbicides break down readily and rapidly in water and pose no threat to human or animal health, there are waiting periods on the use of water treated with most herbicides. These restrictions—mostly on fishing, domestic use, livestock watering, or irrigation—dictate which herbicides will be appropriate for your lake or pond. At the current time there are no swimming restrictions on the herbicides listed in this paper; however, it is always wise to encourage at least a 24-h period before swimmers are allowed back into treated water. Always check the herbicide label for possible restrictions.
3. **Dosage.** Calculate the dosage carefully and do not apply more chemical than is needed. Some aquatic herbicide labels give dosages on the basis of acre-feet (a volume measurement). Acre-feet are calculated by multiplying the surface area by the average depth. For example, a pond with a surface area of 0.5 acre and an average depth of 4 ft contains (4 ft × 0.5 acre) 2 acre-feet. The herbicide label can then be consulted for the amount of chemical to apply per acre-foot.
4. **Timing.** Late spring is usually the best time to apply aquatic herbicides. The plants are young and actively growing and most susceptible to herbicides. Do not wait until July or August! If you wait until late summer to treat, you are running a serious risk of killing fish. By late summer, the vegetation is usually extensive and thick, and the water is warm and still. Killing all vegetation at once under these conditions could seriously deplete the water of its oxygen and cause a fish kill. If you must treat late in the summer, treat only a portion of the weed growth at a time.
5. **Temperature.** Aquatic plants are not affected by herbicides when the water is too cold. The water temperature should be in the 60° F range, preferably the upper 60s (in the area to be treated). These temperatures usually occur from late April to mid-June in the North Central Region. Thus, as soon as the plants are up and actively growing, and if the water temperature is right, the herbicide should be applied.
6. **Retreatment.** More than 1 treatment a season (e.g., copper sulfate on algae) may be required for adequate control. Retreatment is usually required in

succeeding years. Plants can regenerate each spring from seeds, spores, and underground structures. Seeds and underground structures generally are not affected by most aquatic herbicides. Exceptions include Rodeo and 2,4-D that translocate into underground structures and kill them. New plants, however, can sprout from seed.

Aquatic Herbicide Formulations and Application Methods

1. Copper sulfate: granular crystals, diamond form, powder

The granular form is best applied by putting it in a burlap sack and towing it by boat around the pond until it is dissolved.

The powder form is best used by dissolving it in water and spraying directly onto the algae mats and into the water. Copper sulfate is highly corrosive to metals so that plastic, enameled, or copper-lined containers and fittings might be needed for mixing and applying the algicide. Sprayers should be thoroughly cleaned and rinsed out after every operation to prevent corrosion.

2. Cutrine Plus, Algae Pro, Algimycin, K-Tea, and other chelated copper compounds: liquid, granules.

Mix liquid with water in a container and spray or inject into infested area. Granular formulations can be broadcast into the water. Both liquid and granular formulations can be used as spot treatments. Somewhat less corrosive to metals than copper sulfate.

3. Hydrothol and Aquathol: liquid, granules; active ingredient is endothall.

Hydrothol liquid is recommended for use only by commercial applicators. It can cause fish kills and severe skin burns. Also use caution in handling Aquathol liquid, but it is much safer than Hydrothol liquid where fish are present. Spray or inject liquid–water mix into infested area. Liquid and granules can be used as spot treatments.

4. Reward, Diquat: liquid; active ingredient is diquat.

Spray or inject liquid–water mix into infested area. The herbicide can be used as a spot treatment. Spray is used for duckweed control.

5. Sonar: A.S. (aqueous solution), SRP (slow release pellet); active ingredient is fluridone.

Spray or inject liquid-water mix into infested area. Must be applied to entire surface area of ponds. In lakes and reservoirs should be applied to areas >5 acres to prevent dilution. Not satisfactory as a spot treatment. It takes 30–90 d to see results. May get 2 yr of activity.

6. Aquakleen, Navigate: granules; active ingredient is 2,4-D.

Distribute granules evenly over infested area. With few exceptions, 2,4-D liquid formulations are not currently registered for in-water use. Only amine formulations of 2,4-D liquid can be used for vegetation control around water (e.g., drainage ditchbanks); most liquid ester formulations are highly toxic to fish and should not be used around water.

7. Rodeo: liquid; active ingredient is glyphosate.

Rodeo requires addition of a surfactant to liquid–water mix. Spray directly on foliage. Can be used as a spot treatment or as a wipe-on application. Effective only on vegetation that is standing above the surface of the water.

Some General Considerations and Recommendations

1. Always check with your state regulatory agency to determine if additional restrictions have been placed on aquatic weed control chemicals.
2. Algae control is mostly accomplished with a copper-based product. The chelated copper products may be preferable over copper sulfate under conditions of very hard (alkaline) waters.
3. Aquathol and Reward are commonly used for submersed weed control. They can be tank mixed with copper products to control both algae and submersed plants. They also are effective as spot treatments; therefore, they can be used to control vegetation in one area while leaving other areas untreated. They act quickly and burn-down should be visible within a week of treatment. They are extremely short lived in water; therefore, waiting periods to use the water for various purposes are short (Table 1). Their effect is weak on Eurasian watermilfoil.

Table 1 • Aquatic Herbicide Recommendations and Use Restrictions

Aquatic weed	Herbicide	Typical product rate[1]	Restrictions[2]
Algae (microscopic, filamentous, Chara)	Copper sulfate (25% Cu)	2.7 lb/A-ft	Do not use in trout-bearing waters
	Copper chelates	Rate varies with formulation	Do not use in trout-bearing waters
	Hydrothol 191 (liquid) Hydrothol 191 (granular)	0.6 to 2.2 pt/A-ft 3 to 11 lbs/A-ft	F = 3 d; I,L, Sp, D = 7–25 d
Submersed plants (pondweeds, naiads, elodea)	Aquathol K (liquid) Aquathol (granular)	0.6 to 1.3 gal/A-ft 27 to 54 lbs/A-ft	F = 3 d; L, J[4] Sp, D= 7–25 d
	Reward	1–2 gal/SA	I = 1–5 d; D = 1–3 days; L = 1 d
	Sonar	Rate varies with formulations	I = 7–30 d: do not apply within 1/4 mi of potable water intakes
Submersed plants (Eurasian watermilfoil, coontail)	Aquakleen, Navigate	100–200 lb/SA	Do not apply to waters for I, D, dairy animals
	Sonar	As above	As above
Free-floating plants (duckweed, watermeal)	Reward	1 gal/SA; add surfactant	As above
	Sonar (AS formulations only)	1 qt/SA	As above
Rooted-floating plants (waterlilies, spatterdock)	Rodeo + surfactant	Consult label	Do not apply within 1/2 mi upstream of potable water intakes.
Emergent plants (cattails, willows and other perennial plants)	Rodeo + surfactant	Consult label	As above
	Some 2, 4-D amine formulations may be used for broadleaf control.		Do not contaminate water. Check the label.

Permits are required for treatment of public waters in most states. Check with your state regulatory agency for information.

[1] 5A, surface acre; A-ft = acre-feet. These rates are given only as an indication of amount to use and will vary according to target species, recommended dosage, state restrictions, etc. **Please read the label to determine actual rate.**

[2] Additional restrictions can be imposed by states. **Check with local and state regulatory agencies.** F, fishing; I, irrigation; L, livestock; D, domestic, Sp, as spray for crops. Where range of days is given (e.g., 7–25 d), the waiting time depends on dose used (Hydrothol, Aquathol, Reward) or crop to be irrigated (Sonar).

[3] Liquid formulation only: treated water can be used for sprinkling bent grass immediately.

4. Aquakleen and other 2,4-D granular products primarily are used for Eurasian watermilfoil control. Because 2,4-D is selective for the milfoils, native species (pondweeds, naiads, elodea, etc.) other than the native milfoils are generally left unharmed. Therefore, this product can be used to allow some vegetation to remain in a body of water.

5. Sonar controls primarily submersed species. Although it is expensive, it is very effective on Eurasian watermilfoil and can give $\geq$2 yr control. Its selectivity is still questionable; it also may control or injure native species. Check with your state regulatory agency to determine if restrictions have been placed on Sonar use in natural lakes. Sonar cannot be used as a spot treatment, and it is very slow acting.

6. Duckweed and watermeal are difficult to control. Surface applications of Reward primarily burn the plants, but they tend to come back within a week or two. Therefore, continual treatments are required throughout the season, starting as soon as the plants appear on the water surface. Sonar can be much more effective on duckweed than Reward and if used correctly can sometimes provide >1 yr of control. The recommendation for duckweed control calls for use of the Sonar A.S. formulation at 1 qt per surface acre (the Sonar SRP formulation is less effective). Pond outflow must be blocked for at least 30 d or longer because the plant has to be exposed to the chemical for at least this long to be effectively controlled. The dose should be split and applied in 2 applications about 10–14 d apart. SePRO, the company that sells Sonar, guarantees the results on duckweed if its published procedures are followed. For a copy of those procedures, call 1-800-419-7779.

7. Rodeo plus a surfactant is effective on almost all vegetation that stands above the water surface; therefore, it is labelled for emergent and rooted floating plants. Although Reward also is labelled for emergent plant control, it primarily burns the foliage and does not move into the underground parts of the plant. Rodeo, in contrast, does move downward and effectively kills underground structures. This movement is essential for long-term control of the plant. Rodeo acts slowly; therefore, effects on the vegetation may not be seen for several weeks after treatment. A fall treatment (before the first killing frost) on cattails can be very effective. A wipe-on treatment (wear protective gloves to apply the chemical with a sponge directly on the foliage of the target species) protects other nearby species from injury.

Aquatic Plant Identification Guide

Most aquatic plants can be divided into 2 botanical groups: algae and flowering plants. Algae are usually very simple in structure, but some (e.g., Chara) can resemble flowering plants. For effective chemical control, it is essential that you distinguish between algae and flowering plants.

Algae

There are three general types of algae: microscopic algae, filamentous mat-forming algae, and Chara.

Microscopic algae form scums or color the water green or yellow green. Sometimes they can cause red, black, or oily streaks in the water. When in sufficient numbers to color the water they are called blooms. Die-off of these algae can cause fish kills. Blooms usually occur where abundant nutrients (e.g., nitrogen and phosphorus fertilizers) are reaching the water. The best solution for microscopic algal blooms is to prevent the input of nutrient-laden water. If chemical treatment is needed, the algae should be treated with chemicals before they cause a noticeable color. Microscopic algae are not consumed by grass carp.

Chara

Filamentous algae (often incorrectly called moss) form floating, matlike growths that usually begin around the edges and bottoms of bodies of water in the spring. This type of growth is probably the most common in lakes and ponds in the Midwest. Repeated chemical treatments during the summer season are often necessary for effective control. Although grass carp will generally eat submersed rooted plants first, they may eventually begin consuming filamentous algae.

Chara or stonewort usually grows in very hard water and often is calcified and brittle. The plant is rooted and leaves are arranged along the stem in whorls. The plant is completely underwater and has a musky smell. In some bodies of water where it is low growing, it can provide valuable habitat for fish. In shallow water, however, it can grow up to the surface and be troublesome.

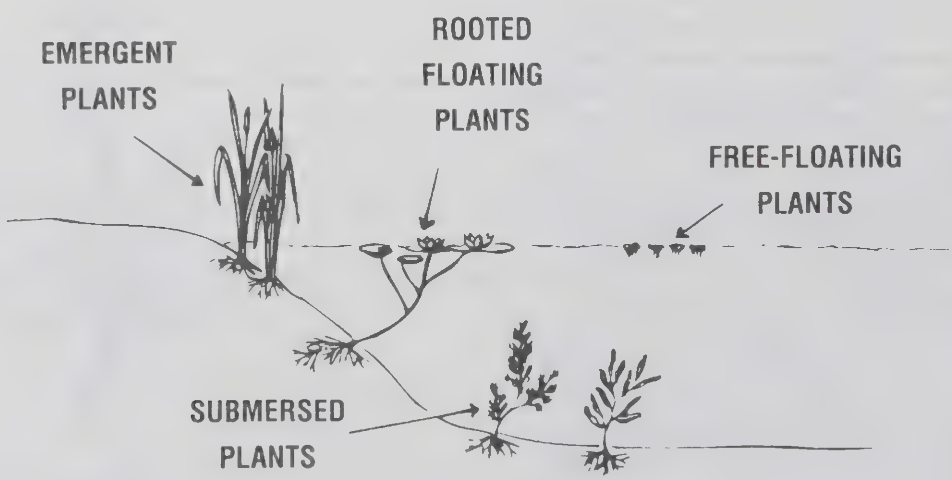
Chara can be difficult to control once it has become established and has a heavy coating of calcium carbonate (limestone). Use copper compounds when the plants are still young and not heavily calcified. Although this plant resembles some flowering plants, it is an alga.

Flowering Plants

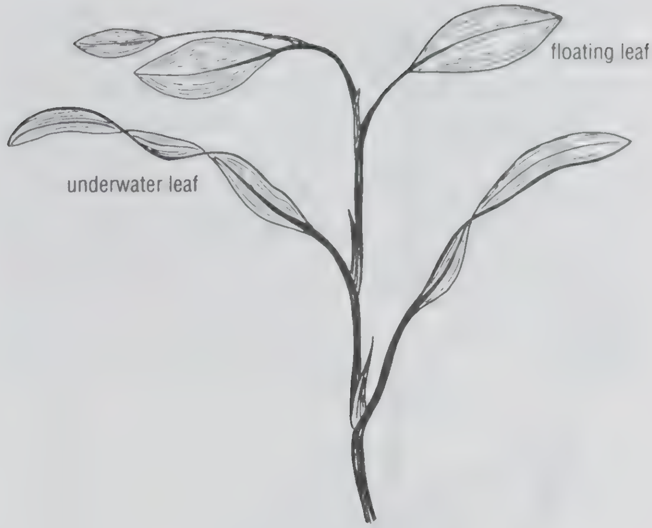
Flowering plants can be grouped into broad categories according to where they are found in a body of water.

Submersed plants are rooted in the bottom sediments and grow up through the water. Flowers or flowering spikes sometimes emerge above the water surface. Some of the pondweeds, such as American pondweed, have both underwater leaves and leaves that float on the water surface. The main criteria for identification are leaf arrangement and leaf shape. The plants shown herein are some of the most common underwater plants with weedy characteristics. Within almost each group, however, there are species that have value for fish or wildfowl habitat. For example, curly-leaf pondweed is considered a weed but beds of large-leaf pondweed can provide good shelter for game fish. Eurasian watermifoil is a very aggressive, introduced weed, but other milfoil species are native and have less potential as weeds. Information beyond what this paper provides is necessary for complete aquatic plant identification.

Curly-leaf pondweed: Alternate leaf arrangement (1 leaf per node). Grows best in the spring and tends to die out in the summer. Common in ponds, lakes, and ditches.



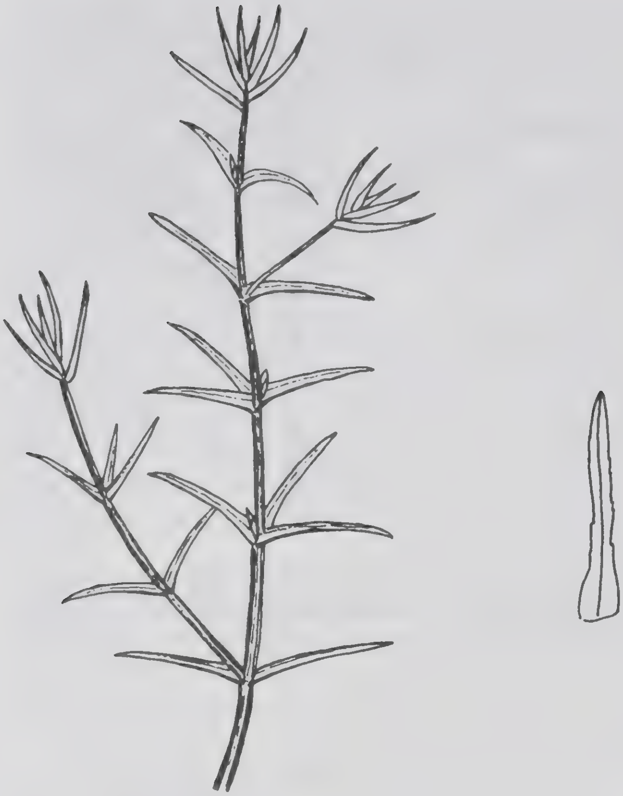
Leafy pondweed: Very narrow leaves; alternate leaf arrangement. More common in ponds than in large lakes.



American pondweed: Leaves that float on top of the water surface are ≈1–4 in. in length. Usually restricted to shallow water.

Sago pondweed: Leaves are almost threadlike. Individual leaves tend to be slightly curved. Although a weed in some situations, the seeds and underground tubers are valuable as food for waterfowl.

Brittle naiad: Opposite (2 leaves per node) leaf arrangement; sometimes 3 leaves appear at a node. Leaves slightly spined. More common in southern portions of the North Central Region.



Southern naiad: Opposite leaf arrangement; sometimes appearing as 3 leaves per node. Very common in lakes and ponds.

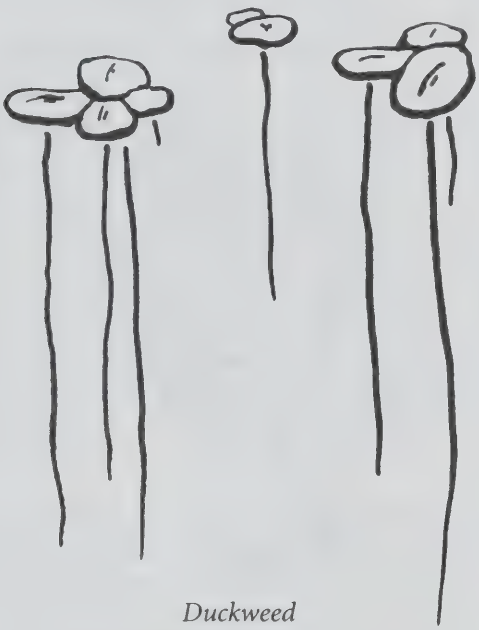
Coontail: Whorled leaf arrangement (>2 leaves at a node); leaves branched and spined. Very lightly rooted or floating in the water column. Very common in shallow, marshlike areas.

American elodea: Three leaves at a node. Very common in lakes and ponds.

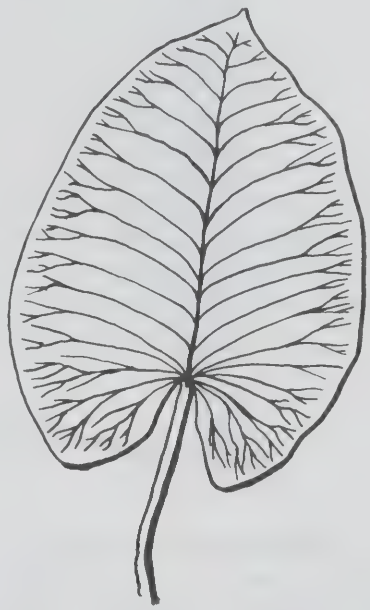
Eurasian watermilfoil: Featherlike leaf with 4 leaves at a node. A serious and rapidly spreading invader. Found in lakes and ponds throughout the North Central Region. Eurasian watermilfoil typically has >10 leaflet pairs per leaf, whereas native milfoils have <10.

Free-floating plants such as duckweed and watermeal can completely cover the surface of a pond. Complete surface coverage by these plants shades out underwater plants, thus causing oxygen depletion in the deeper water. These plants are extremely small. Duckweed is no more than 0.25 to 0.5 in. in diameter and watermeal is even smaller. Duckweed plants have a small root that hangs into the water. Watermeal plants have no roots and look like tiny green seeds or green cornmeal. Both plants are found in nutrient-rich waters; therefore, the input of waste water from feedlots, septic fields, etc. should be eliminated for effective control. These plants are very difficult to control with chemicals.

Rooted-floating plants include waterlily, spatterdock, and water lotus. Spatterdock is usually the more aggressive of the 3 plant species and can completely fill in shallow areas <3 or 4 ft in depth. Spatterdock has a massive underground rhizome from which new plants can sprout. It differs from waterlily in having a heart-shaped rather than round leaf, and the leaves come above the surface of the water rather than float. Spatterdock has yellow flowers. This group of plants provides wildlife habitat and may be protected, particularly in natural lake and wetland areas.

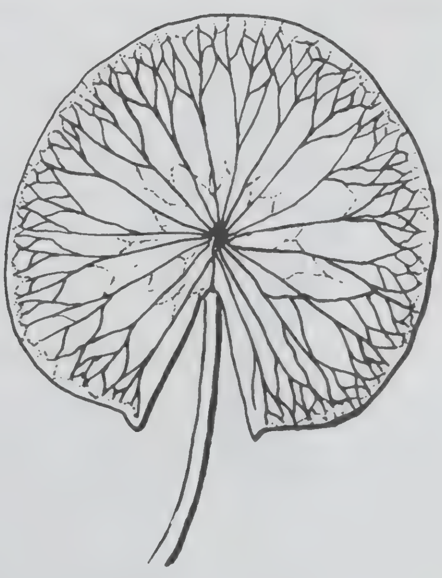


Duckweed



Spatterdock

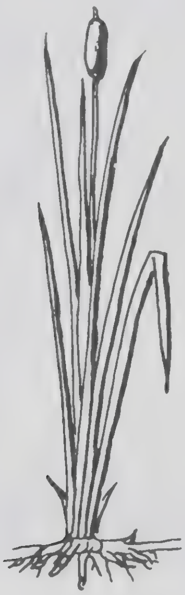
Watermeal



Waterlily

Emergent (shoreline or marginal) plants include grasslike and broadleaved plants. Grasslike plants commonly include cattails, bulrushes, spikerushes, and reed canarygrass. Broadleaves include willow trees, creeping water primrose, and purple loosestrife. Purple loosestrife is an invader of wetland areas, has no wildlife value, and is considered a serious weed. All of these plants spread rapidly by underground systems as well as by seed.

Bulrush (2 types): Plants 3–7 ft in height.



Cattail: Plants 5–7 ft tall.

Creeping water primrose: Plants low growing in shallow water. Flower color is yellow.

Spikerush: Plants usually no more than 1 ft in height.

Purple loosestrife: Plants in wetland areas, ≈4 or 5 ft in height. Flower color is purple.

INTERNET RESOURCES FOR PEST MANAGEMENT

David R. Pike

The Internet continues to grow by leaps and bounds. At the time of this writing there were over 8 million separate web sites providing information, and it is evident that the task of locating what you want when you want it continues to be a challenge. The media is replete with stories about the "dark side" of this technology and of the time and resources that can be wasted when it is ill-used. My objective is to list some of the sites on the World Wide Web (WWW) that I have found useful with the hope that they might prove to be a time-saving resource to you as well.

The web sites below fall into 2 general resource categories: local and global. When seeking to answer a question or to develop a solution to a problem I encourage you to seek out information from the most local resource available, such as by contacting a web site in your county, region, or state before pursuing national or international WWW resources. If the resource exists locally, it may provide information tailored to your specific needs. If you have questions about the information provided and need to ask questions for clarification, people supporting local web sites in general are more likely to be helpful to "surfers" from their own area. Questions you address to the Webmaster tend to be answered sooner with more relevant information. In addition, if the information is not available locally there are usually links to parent or sister organizations that can provide the data.

I recommend that you investigate some local web sites as well as the sites listed in this paper. Local extension and Farm Bureau offices, agrichem dealers, and suppliers may all have web pages. Make sure that you visit your competitors web site and keep up with what they are up to as well. Set your bookmarks to those sites you find of interest. If you don't find what you are looking for at first, check back from time to time as all web sites are constantly being changed and updated. This paper lists my favorite sites, all of which have a number of links to other useful sites. Only a few of the topics available on each site are listed.

Statewide Resources

Weather

Topics include numerous weather maps, radar images, records, outlooks, and severe weather. Useful links include weather sites in other geographical areas.

http://redrock.ncsa.uiuc.edu/AOS/home_weather.html

The Illinois Corn Page (Illinois Corn Growers Association)

Topics include current corn production and processing research, market info, legislation pertinent to corn production, and corn production facts and figures. Useful links go to other commodity organizations and related industries.

http://www.ilcorn.org/

The Stratsoy homepage

Topics include current research on production and processing of soybeans [*Glycine max* (L.) Merrill] , market info, legislation pertinent to soybean production, and facts and figures. The site has an "Ask the expert" section and threaded queries. Useful links go to other commodity organizations and related industries.

http://www.ag.uiuc.edu/~stratsoy/new/home.html

University of Illinois Crop Science Extension

This site contains information about weeds, insects, crop diseases, variety selection, and soil fertility in the state of Illinois. Information is available in fact sheets and research summaries and can be searched with a search engine. The site provides a question and answer forum and threaded queries to allow visitors to follow current production or pest management issues. It provides links to many of the sites listed herein.

http://ext.agn.uiuc.edu/extension/index.html

Illinois Fertilizer and Chemical Association

This site contains information on legislation dealing with Illinois agrichemicals, MAGIE, fertilizer issues, IFCA membership, calendar, and the CCA program.

http:www.ifca.com/

Illinois Farm Bureau

This site contains topics on legislative issues, markets, and Illinois ag facts and figures. It has useful links to Illinois commodity groups and state government offices and universities.

http://www.fb.com/ilfb/

Global Resources

Search engines: Altavista, Infospace, Excite, Infoseek, Yahoo

Each search engine has general topic lookup as well as business and people indices.

Argisurf

Agrisurf is an internet subscription service. You choose the topic and current information is pulled off the internet and sent to you via email on a regular basis. This service provides general information about agriculture along with a good deal of advertising.

http://www.agrisurfer.com/

Argus Clearinghouse

This site provides a topical guide (encyclopedic) access to the Internet for topics of all kinds. Agriculture is not a principal focus but this site may be useful in many ways.

http://www.clearinghouse.net/

Professional Organization Resources

Entomological Society of America

The Entomological Society of America site contains general information about the society and its membership. It is a good source for general information and pictures of insects of all kinds. For research related to insects in field crops or horticultural crops see your state extension links.

http://www.entsoc.org/

Weed Science Society of America

This site contains general information about the Weed Science Society of America and its membership. It is a good source for general information and pictures of weeds of all kinds. It also contains links for issues related to herbicides and related technology. For research related to weeds in field crops or horticultural crops see your state extension links.

http://ext.agn.uiuc.edu/wssa/

American Plant Pathology Society

This site contains general information about the American Plant Pathology Society and its membership. It also has general information about plant diseases with a number of links to other sites providing more detailed plant disease information.

http://www.scisoc.org/

The American Society of Agronomy

The American Society of Agronomy site has information on certification, public policy, and legislative issues. The site also contains a number of useful links to colleges and universities, government, research institutions, journals, international resources, and nonprofit organizations.

http://www.agronomy.org/

The United States Environmental Protection Agency

The United States Environmental Protection Agency (US EPA) site has information on policy, current research, projects and programs, laws and regulations, lists of banned products, publications, and databases. Links to regional EPA offices also may be useful.

http://www.epa.gov/

The United States Department of Agriculture

This site has information on Y2K, United States Department of Agriculture (USDA) legislation, disaster assistance, USDA publications and educational resources, U.S. markets and U.S. ag facts and figures. It also has links to ARS, ERS, NASS, CSREES, FS, and USDA local offices.

http://www.usda.gov/

The American Crop Protection Association

This site has information on FQPA, FIFRA, water quality, pesticide safety fact sheets, and American Crop Protection Association publications. This site also has links to ag companies, biotech, commodity organizations, news and Media, crop protection companies (chemical).

http://www.acpa.org/

Agriculture Network Information Center (AgNIC)

This site is a distributed network that provides access to agriculture-related information, subject area experts, conferences and meetings, on-line reference service for many minor crops, sustainable ag, and other resources.

http://www.agnic.org/

WEEDS 2000: WHAT'S ON THE HORIZON?

Aaron Hager

Three things in life are certain: death, taxes, and weeds. Each growing season presents new and sometimes unique weed management challenges in addition to the more traditional headaches. Weed science and weed management are experiencing a dynamic epoch that promises exciting new technological developments. Yet with all the myriad of new discoveries, weeds continue to present significant challenges to production agriculture. In the politically correct decade of the 1990s, maybe we should consider weeds as "alternative vegetation."

As crop management programs change, many weed management decisions also change. The diversity of weed species and populations ensures that some type of alternative vegetation will adapt to changes in agronomic crop production systems. Three broad categories of weed adaptation include the development of herbicide-resistant weed biotypes, shifts in weed spectrum, and establishment of new or previously obscure weed species. Each of these categories will contribute to new weed management problems and opportunities during the next century.

Development of Herbicide-Resistant Weed Biotypes

The occurrence of herbicide-resistant weed biotypes continues to increase in Illinois. Although some debate the distinction between resistance versus tolerance, the producer deals with the adverse consequences of weeds no longer controlled by previously effective herbicides. The majority of herbicide-resistant weeds in Illinois demonstrates resistance to 1 of 2 predominant herbicide families: triazine herbicides or herbicides that inhibit the acetolactate synthase (ALS) enzyme. There are even a few biotypes that have demonstrated resistance to both triazine and ALS-inhibiting herbicides. Species with biotypes resistant to triazine herbicides include smooth pigweed (*Amaranthus hybridus*), common lambsquarters (*Chenopodium album*), and kochia (*Kochia scoparia*). Species with biotypes resistant to ALS-inhibiting herbicides include common and tall waterhemp (*Amaranthus rudis* and *A. tuberculatus*), smooth pigweed, common cocklebur (*Xanthium strumarium*), and kochia.

The development of herbicide-resistant weed biotypes is an example of how a particular weed species is able to adapt to changes in its environment. These changes are imposed to a large extent by our weed management approaches. Practices that rely exclusively on a single herbicide mode or site of action with no other effective management mechanisms exert a greater amount of selection pressure compared with practices wherein multiple modes or sites of herbicide action are used in conjunction with other nonchemical management tactics. Three factors that influence the degree of selection pressure imposed by a herbicide include the effectiveness of the herbicide, the frequency of use, and duration of effect. In plants, heritable variation for the trait that confers resistance must be present and persist through generations of natural selection. Thus, many examples of herbicide-resistant biotypes originate from weed species that demonstrate a wide range of genetic diversity (e.g., waterhemp, shattercane).

There are numerous sources of available information on the topic of herbicide-resistant weed biotypes. For those with access to the World Wide Web, Ian Heap (IanHeap@WeedSmart.com) maintains a web site (http://www.weedscience.com/) with detailed informa-

tion on herbicide mode of action as well as extensive information on herbicide-resistant weeds.

We are often asked about the potential to select for weed biotypes with resistance to glyphosate, the active ingredient in Roundup®. Most weed scientists agree on 2 points regarding glyphosate resistance: (1) the potential for developing weed biotypes with resistance to glyphosate is much lower than for other herbicide families, and (2) never say it will never happen. Glyphosate has been extensively used throughout much of the world for many years without the development of any resistant biotypes, until a glyphosate-resistant biotype of rigid ryegrass (*Lolium rigidum*) was recently identified in Northern Victoria, Australia. Although glyphosate resistance in this biotype has been confirmed under controlled conditions, the mechanism of resistance has yet to be conclusively identified. Differences in glyphosate uptake, translocation, and metabolism between the resistant and a susceptible biotype were not great enough to account for the 6- to 10-fold resistance. Albeit rare, the development of a glyphosate-resistant weed biotype has occurred and should serve as a warning that this phenomenon is possible. The field were this biotype was identified had received 10 glyphosate applications during the 15 yr prior to the biotype's isolation.

Although it appears certain that debate will continue over whether a glyphosate-resistant weed biotype will be identified in the United States, other consequences of repeated glyphosate use should be addressed, as some of these consequences are likely to occur rapidly. Of particular concern is the likelihood that a shift in weed spectrum may rapidly develop in fields repeatedly treated with glyphosate. This topic is further discussed in the following section.

Shifts in Weed Spectrum

The diversity of weed species encountered commonly in agricultural production systems nearly ensures that some specie(s) will adapt to changes in a particular production system. For example, with the elimination of tillage operations, many no-till fields soon develop populations of perennial weed species, such as hemp dogbane (*Apocynum cannabinum*). Decreased occurrence of large-seeded broadleaf species, such as common cocklebur, can often be observed with a concomitant increase of small-seeded species, such as various pigweed species. Significant changes in herbicide programs can induce a similar shift in weed spectrum.

A current example of how a species can adapt to changes in agronomic systems is waterhemp. This weed (Both common and tall waterhemp are present in Illinois, but they are difficult to distinguish.) was historically most prevalent in the southern third of Illinois, extending north along the Missouri and Iowa borders. Ten years ago, it would have been difficult to find anyone who would have ranked waterhemp as a significant weed problem in either corn (*Zea mays* L.) or soybean [*Glycine max* (L.) Merrill]. Yet within a span of 4 to 5 yr, waterhemp has increased in both prevalence and severity of infestations across three-fourths of Illinois. This southern Illinois only weed problem can now be encountered north of Interstate 80. How has waterhemp been able to spread so rapidly and extensively?

Several factors have contributed to the spread of waterhemp. Although it is true that biotypes of waterhemp resistant to ALS-inhibiting and triazine herbicides have been identified, other factors have allowed this weed to become the predominate pigweed problem in many corn and soybean fields. Having small seeds, waterhemp emerges from shallow soil depths. Elimination of tillage allows seeds to remain near the soil surface until favorable conditions for germination occur the following spring. Many older (especially soil-applied) herbicides have good efficacy on waterhemp, but their use has declined over time as new herbicide options have been marketed. Some of these new herbicide options have selected for herbicide-resistant biotypes of waterhemp, whereas others lack significant soil residual activity that allows waterhemp emergence later during the growing season. Waterhemp represents a species that has become more important through adaptation to changes in production systems (limited tillage), development of herbicide resistance (ALS-inhibiting herbicides, triazine herbicides), and changes in herbicide use patterns (fewer soil-applied and more postemergence herbicides).

There are other examples of weed species shifts or adaptations to changes in production systems. Kapusta and Krausz (1993) noted several differences or shifts in weed species over an 11-yr period under conventional, reduced, and no-tillage soybean production systems.

If dramatic shifts in herbicide use are realized in the near future, one very probable shift will be towards increased use of postemergence herbicides, which lack significant soil residual activity. In particular, the increased use of glyphosate in glyphosate-resistant corn and soybean could potentially shift the weed spectrum in 1 of 2 ways. First, weed species that glyphosate is not particularly effective against could increase in abun-

Table 1 • Hophornbeam copperleaf control and soybean injury at 28 d after treatment at Topeka in 1995 and Junction City in 1995 and 1996.

				Weed control			Soybean injury		
					Junction City			Junction City	
Herbicide	Rate	Adjuvant	Adjuvant rate	Topeka	1995	1996	Topeka	1995	1996
	lb a.i./A.		*%vol./vol.*			*Percent*			
Raptor	0.03	NIS[1] + 28%N[1]	0.25 + 2.5	3	15	0	1	0	0
Blazer	0.125	NIS	0.25	94	78	81	0	1	0
	0.25	NIS	0.25	96	84	93	1	0	0
Basagran	0.5	COC[3]	1.25	0	0	0	0	0	0
	1	COC	1.25	0	4	0	0	0	0
Action	0.004	NIS + 28%	0.25 + 2.5	13	5	0	1	0	0
Expert	0.07	NIS + 28%	0.25 + 2.5	3	3	0	0	0	0
Classic	0.008	NIS + 28%	0.25 + 2.5	5	0	0	0	0	0
Resource	0.027	NIS	0.25	8	0	0	0	0	0
	0.04	NIS	0.25	6	0	0	1	0	0
Reflex	0.125	NIS	0.25	94	88	80	0	0	0
	0.25	NIS	0.25	97	94	84	0	0	0
Scepter	0.122	COC	1.25	5	0	0	1	0	0
Pursuit	0.063	NIS + 28%	0.25 + 2.5	0	4	0	0	5	0
Cobra	0.063	COC	1.25	94	76	96	16	4	3
	0.094	COC	1.25	96	91	98	20	4	3
	0.187	COC	1.25	96	96	98	19	11	3
Pinnacle	0.004	NIS + 28%	0.25 + 2.5	3	0	0	4	1	0
2,4-DB	0.03	NIS + 28%	0.25 + 2.5	3	0	0	4	1	0
	0.063	3	—	0	5	—	0		
	0.125	5	—	0	14	—	0		
LSD(0.05)	7	7	3	4	6	3			

Data reproduced from Table 1 in Horak et al. (1998).

[1]NIS, X-77 surfactant, Valent USA Corp., P.O. Box 8025, Walnut Creek, CA 94596-8025.

[2]28%N , UAN liquid nitrogen fertilizer.

[3]COC, crop oil concentrate was Farmland Oil Concentrate Plus with 17% emulsifier; Farmland Industries, Inc., Kansas City, MO 64116.

dance and severity. If glyphosate effectively controls most annual and several biennial and perennial species, only species with resistance to glyphosate (discussed previously) or that are not easily controlled by glyphosate will be able to produce seed for future generations. At field use rates of glyphosate, control is marginal for the following species: velvetleaf (*Abutilon theophrasti*), morningglory (*Ipomoea* spp.), Pennsylvania smartweed (*Polygonum pensylvanicum*), eastern black nightshade (*Solanum ptycanthum*), and prickly sida (*Sida spinosa*). If these are the only species that survive after repeated applications of glyphosate, it is likely that these species may soon become the dominant weeds in producers' fields. Second, with the limited soil residual activity of glyphosate, weeds emerging after application either remain uncontrolled or require a subsequent glyphosate application. Because glyphosate has limited soil activity, it does not add additional selection pressure for selecting resistant biotypes, but it does favor development of weed species that can emerge late in the growing season, such as eastern black nightshade, waterhemp, and prickly sida. Whether we have the development of herbicide-resistant biotypes develop or there is merely a shift to less susceptible species, the producer is still left with difficult weed management decisions.

Establishment of New or Previously Obscure Weed Species

Each growing season, several weedy plant samples are received at the University of Illinois Plant Clinic for

identification. Over the past 5 yr, 2 species have been received with increasing frequency; hophornbeam copperleaf (*Acalypha ostryifolia*) and toothed spurge (*Euphorbia dentata*). More information is now available on the biology and control of hophornbeam copperleaf.

Hophornbean Copperleaf

Hophornbean copperleaf is a summer annual species of the family Euphorbiaceae. It is sometimes referred to as Virginia copperleaf (*Acalypha virginica*), but the 2 species are distinct. Virginia copperleaf also is referred to as three-seeded mercury because of its 3-lobed, 3-seeded capsules.

Hophornbeam copperleaf has pubescent cotyledons and true leaves with short hairs and finely toothed (serrated) margins. The leaves are simple and alternate and somewhat heart-shaped at the base. Additionally, a reddish coloration is often observed where the main leaf vein intersects the petiole. The plant is monoecious, with staminate (male) flowers produced on axillary spikes and pistillate (female) flowers on a long, terminal spike. Seeds pods of hophornbeam copperleaf are dehiscent (i.e., pods split open at maturity to release seed), and seeds appear to require warm temperatures for germination. A warm-soil-temperature germination requirement may suggest that this species is able to germinate and emerge later in the growing season. Horak et al. (1998) reported that the mean hophornbeam copperleaf seed production by plants growing alone (without competition) was ≈12,518 seeds per plant, much greater than the average seed production (980 seeds per plant) when grown under competition with soybean.

Data are limited regarding herbicide efficacy on hophornbeam copperleaf. Some herbicide labels may list Virginia copperleaf under weeds controlled, but not hophornbeam copperleaf, or vice versa. Horak et al. (1998) contains information on the efficacy of 13 postemergence soybean herbicides for hophornbeam copperleaf control. The results of their field research are reproduced in Table 1. The common names of herbicides have been changed to trade names for clarity, and metric units have been converted to English units. These data suggest that diphenyl ether herbicides (Blazer, Cobra, Reflex) provided the greatest control of hophornbeam copperleaf, with Cobra at the 12-oz rate consistently providing >95% control. Soybean injury can be a concern with greater rates of Cobra, and loss of soybean leaves may allow sufficient light to reach the soil surface. This injury, coupled with precipitation and the later emergence pattern of hophornbeam copperleaf, may in some instances allow additional weed emergence to occur. Roundup®, used in conjunction with glyphosate-resistant soybeans, may be another viable postemergence herbicide option for hophornbeam copperleaf control (Dallas Peterson, Kansas State University, personal communication). With no soil residual activity, however, additional flushes of copperleaf may occur under the right conditions. Suflentrazone appears to be a good soil-applied herbicide option.

Data are limited on corn herbicides for hophornbeam copperleaf control. In previous work at Oklahoma State University (1971), Atrazine performed well, but present-day application rates may not provide sufficient residual control for a species that can emerge late in the growing season. Postemergence applications of atrazine and oil also can provide control, but again, application timing restrictions may reduce the effectiveness of this treatment.

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DIPLODIA EAR ROT OF CORN

Dina E. Severns and Don G. White

Diplodia ear rot of corn (*Zea mays* L.) caused by the fungus *Stenocarpella maydis* (*Diplodia maydis*), is a corn disease that was serious in the 1930s through the 1950s. Since the 1950s the disease has virtually disappeared from most of the upper Midwest, largely because of fall plowing. During the late 1970s and early 1980s, the disease again began to occur in southern Ohio and Indiana, mostly along rivers. This increase was associated with the adoption of conservation tillage. Diplodia ear rot has occurred in Illinois for the last several years and was common in some areas of the state during the 1998 growing season.

Fusarium ear rot, caused by *Fusarium moniliforme*, is probably the most common corn ear rot disease. Gibberella ear rot, caused by *Gibberella zeae*, is common in some areas of the Corn Belt. *F. moniliforme, G. zeae*, and *S. maydis* all cause stalk rot of corn and are commonly associated with corn stalk debris. *S. maydis* only has corn as its host, whereas *F. moniliforme* and *G. zeae* may be found associated with numerous grass hosts. In addition, *S. maydis* is a very poor saprophyte and cannot compete well with other fungi in soil. In contrast, *F. moniliforme* and *G. zeae* are very good saprophytes and can maintain populations in soil. Therefore, unlike *F. moniliforme* and *G. zeae, S. maydis* is highly dependent upon corn as a host and on corn residue on the soil surface for its survival.

Diplodia ear rot occurs when pycnidia on corn stalks previously diseased by Diplodia stalk rot remain on the soil surface and produce spores during the growing season. If rain occurs shortly after flowering, spores of *S. maydis* are splashed from corn stalks on the soil surface to silk and ear tissue. For many years it was thought that *S. maydis* only penetrated into silks as they senesce after flowering. We now suspect that the fungus also may grow between the ear shoot and the stalk eventually penetrating the ear through the husk leaves.

Symptoms of Diplodia ear rot are different from those of other common ear rot diseases. Husks of infected ears often appear bleached or straw colored with white to gray-brown fungal growth over the husk and kernels. The entire ear may be shrunken and turn grayish brown with the infected kernels appearing glued to the husks by the mycelium of the fungus. Black pycnidia are produced later in the season on husks, kernels, cobs, and rotted silks. If infection occurs just prior to maturity, the ears may show little or no external symptoms. Kernels of these ears may be asymptomatic even if the fungal mycelium is found between the kernels. Economic losses may occur as the result of low test weight or discounts due to damaged kernels. Fortunately, *S. maydis* is not known to produce mycotoxins that result in animal health problems when damaged grain is consumed.

Because Diplodia ear rot has not been a serious disease of corn in Illinois for the last 30 yr much of the used corn germplasm has not been intensively evaluated for resistance or susceptibility. Several methods have been used to inoculate corn and we are evaluating one such method. For our experiment we used 29 commercially grown corn hybrids (Table 1). For the purpose of this paper the identity of the hybrids has been masked because our goal is to determine the range of susceptibility and not to recommend hybrids for resistance. Several of the hybrids were included because of suspected problems with susceptibility; others were chosen to represent diversity in germplasm or wide use. The 29 hybrids were planted in mist-irrigated plots in a completely randomized block design with 2 replicates at the Crop Sciences Research and Demonstration Center in

Table 1. Susceptibility of corn hybrids to Diplodia ear rot.

Corn Hybrid	Bleached husks (%)[1] 1997	Bleached husks (%)[1] 1998	Completely mummified ears (%)[2] 1997	Completely mummified ears (%)[2] 1998	Harvest ratings[3] 1997	Harvest ratings[3] 1998
23594	4.0	4.5	0.0	0.0	1.6	1.7
23521	13.8	6.3	0.0	0.0	2.5	4.2
23552	23.8	7.1	5.0	0.0	4.3	2.8
64021	28.8	14.0	2.5	2.5	3.2	1.3
64021	30.5	14.2	4.6	0.0	5.7	1.9
G1752	26.3	14.5	2.5	0.0	2.6	2.2
23317	22.9	16.4	2.1	2.8	3.7	2.2
24021	35.4	18.6	7.2	4.8	3.7	2.2
23585	27.6	22.8	7.7	8.9	3.9	3.3
03225	18.7	24.2	2.7	2.5	2.3	2.2
03335	26.6	28.7	4.7	2.8	4.3	3.2
52617	31.7	30.7	4.9	9.1	3.6	2.6
03245	27.6	31.6	0.0	0.0	3.6	2.7
50617	48.9	32.7	15.9	53.0	4.2	4.3
G1717	29.2	34.6	0.0	5.4	2.3	4.6
33652	69.2	35.6	49.6	38.1	6.8	5.1
03489	38.8	37.0	15.7	23.9	3.9	3.0
50185	64.6	38.6	35.6	52.3	4.7	4.5
21371	43.8	40.0	11.3	11.7	4.6	3.6
64652	63.6	40.6	29.7	9.4	4.3	2.7
19872	55.2	40.9	28.4	43.6	3.6	3.8
64218	40.1	44.7	5.0	10.6	3.7	2.1
33185	71.3	45.9	47.3	44.1	6.1	5.0
23372	61.5	46.7	32.1	29.6	4.6	3.3
64697	61.3	47.7	30.0	18.2	4.7	3.9
40185	63.1	47.9	36.3	52.1	3.7	6.0
62185	59.0	58.1	27.2	37.2	6.3	3.8
50653	50.1	59.8	12.9	21.4	4.7	3.3
64185	46.4	66.5	21.5	22.1	4.0	3.9
LSD .05	13.859	18.345	17.853	13.13	1.30	1.03
CV	16.5118	27.30879	56.186	36.74384	15.73324	15.29773

[1] Percentage of plants with evidence of Diplodia ear rot on husk tissue.

[2] Percentage of ears completely rotted.

[3] Average visual estimate of severity of harvested ears (1–9 scale) when 1 = 0–10% . . . 9 = 90–100% of the ear rotted.

Urbana. For inoculation in 1997, we produced inoculum by growing *S. maydis* on sterilized oats (*Advena* spp.) in the laboratory. After several weeks of growth the oats were dried and used as inoculum. In 1998 we used previously inoculated, diseased ears that were dried and then ground in a forage chopper. In both years, the oats or ground, diseased ears were placed in the whorl of plants several weeks before flowering so that the inoculum would be close to the ear shoot when plants flowered. The irrigation water provided splashing for dissemination of spores from the inoculum to developing corn ears. Five weeks after flowering, the number of ears with bleached or straw-colored husks was recorded and converted to a percentage. The number of of ears that were completely rotted (mummified) by the fungus were counted and converted to a percentage. At harvest, 18 ears per row were rated for ear rot severity by using a scale where 1 = 0–10% to 9 = 90–100% of the ear rotted. The mean of the 18 ears was used as the mean for the replicate.

The level of disease was severe in both years (Table 1). There was general agreement between years in hybrids that were most susceptible or most resistant. It appears from these studies that we have a reliable inoculation technique. Also, considerable variation exists within usable commercial hybrids, although most are susceptible. The hybrids 23594, 23521, and 23552 have a common female parent that seems to confer resistance. Likewise, several of the more susceptible hybrids have parents in common.

The demand for resistant hybrids by farmers in Illinois is not known at this time. Diplodia ear rot usually is only a problem with wet weather following flowering in fields where stalk debris is on the soil surface. Because the disease is sporadic in its occurrence, highly resistant hybrids need not be demanded. We suggest that hybrids be evaluated for susceptibility and those that are very susceptible not be planted in fields where inoculum from corn plants previously diseased by Diplodia stalk rot may be present.

ILLINOIS SOYBEAN CYST NEMATODE COALITION

Rebecca Richardson

Soybean cyst nematode (SCN) is a parasitic disease that has been prevalent in the southern half of the country over 40 yr, and in southern Illinois for >2 decades. For the last 10 yr, University of Illinois (UI) Extension, College of Agricultural, Consumer and Environmental Sciences (ACES), has reported that in areas where SCN is present, Illinois soybean producers are losing an estimated 4–6% of their total yields to SCN. Individual farmers have reported greater losses. Sampling conducted by UI Extension also indicates SCN has spread to central and northern areas of the state, and has been found in soil samples from all but 4 extreme northern Illinois counties.

The toughest challenge of managing SCN infestation is that it is non-symptomatic. By the time above ground symptoms are visible, the damage to yield and plant health has been done. A perfectly healthy looking field of soybeans could be performing significantly under its potential, and a grower might never know it is infected. In rich soil, it is often difficult to tie loss to SCN because there are so many factors that can account for the same ratio of loss, such as moisture, soil type and condition, or other pest problems. It is difficult to convince some growers that they may have SCN, and that they need to sample their soil for its presence.

Regional SCN Coalition

The SCN Coalition originated from funding provided by the North Central Soybean Research Program (NCSRP), a 10-state alliance of state soybean checkoff boards that finances soybean research projects. In 1997, the 10-member farmer board designated SCN a priority and approved the creation of an education and awareness program. The goal of this program is to get producers to test their fields for SCN and if they have it, to act on managing it.

The regional SCN Coalition includes state soybean checkoff boards from Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Nebraska, Ohio, South Dakota, and Wisconsin. The industry partners are the American Soybean Association; Asgrow Seed Company; Cargill Seeds; Cenex/Land O'Lakes; DEKALB Genetics; Growmark; Mycogen Seeds; Pioneer Hi-Bred International, Inc.; and the United Soybean Board.

Illinois SCN Coalition

Each of the 10 states making up the regional SCN Coalition has a state structure to support and deliver the education and awareness program to growers in that state. Although 9 of the 10 states have adopted the strategy of using the land-grant university and researchers from these institutions to implement their state programs, Illinois has developed a state coalition with many public and private-sector partners to reinforce the importance of testing for SCN. Although the network is complex and offers communication and management challenges, the Illinois Soybean Checkoff Board (ISCB) determined it was an investment that was necessary to achieve the end result of action by soybean growers.

The Illinois SCN Coalition partners are the Illinois Seed Trade Association; Illinois Soil Testing Association; Illinois Soybean Association; Illinois Soybean Checkoff Board; and University of Illinois Extension, College of ACES. Within each of these umbrella organizations, many cooperators have agreed to participate, including

24 private soil testing laboratories and 20 state or regional seed companies. Each partner plays a vital role in the overall success of the state as well as the regional program.

State Partners

The Illinois Seed Trade Association provides the capability to communicate to seed companies throughout the state about the SCN Coalition and the benefits it offers to soybean growers. Through the Illinois Seed Trade Association, 20 seed companies to date have agreed to provide information to growers. Many of the seed companies have requested training for their agronomists and sales force, who will distribute SCN literature through each of their customer networks.

The Illinois Soil Testing Association provides the framework necessary to analyze the influx of soil samples that will be generated by the efforts of the SCN Coalition. A critical difference between the Regional Coalition and the Illinois Coalition is the amount of soil testing being encouraged. The goal of the regional effort is awareness and any level of testing will achieve this goal. Because the economic impact in Illinois is so significant, the state goal is to aggressively pursue thorough testing of fields being planted to soybeans to not only determine if but also where and to what extent SCN exists. To accomplish this goal, the Illinois Coalition envisioned a system to collect and analyze soil through private laboratories that would then forward the results to a central SCN databank, managed by UI Extension. Additionally, the private soil test laboratories retain their own customers and relay the test results to them directly.

The Illinois Soybean Association provides staff to manage all components of the Illinois SCN Coalition and to provide communication between the various partners and cooperators.

The Illinois Soybean Checkoff Board is the primary funding source for the Coalition, providing financial support through matching programs and sponsorships for various events, including field days, county ag days, and state fair and farm shows. The ISCB also is funding 3 major data collection and education projects in the state targeted at different audiences, including farm managers, seedsmen, and growers.

UI Extension, College of ACES, oversees all aspects of SCN training and management practices for the entire spectrum of the production chain, including growers as well as industry service providers. The UI Extension also maintains the SCN databank at the University of Illinois and is responsible for collecting and reporting results of all SCN testing. Additionally, UI Extension is the lead organization for collecting industry information, such as the release of new SCN-resistant soybean varieties. They partner with the Illinois Soybean Checkoff Board to release information to all soybean growers in Illinois.

Worth the Investment

The monies earmarked for this project—nearly $1 million each year for 3 yr—represent a fraction of the dollar value lost annually to SCN. In Illinois, where 428 million bu of soybean was produced in 1997, projected loss from SCN was between $112,000,000 and $168,000,000 million according to UI Extension. Although numerous articles have appeared in the media and UI Extension has urged growers for many years to test for SCN, research findings consistently indicate that more needs to be done. A different approach is necessary. With the combined efforts of the coalition partners, more growers can not only be reached but also motivated to test for and manage SCN. The SCN Coalition urges producers to "Take the Test. Beat the Pest."

SOYBEAN CYST NEMATODE: SPREAD AND DISSEMINATION

Dale Edwards

The soybean cyst nematode, *Heterodera glycines* (SCN), is an extremely devastating pest of soybean. Since its initial discovery in the U.S. in 1954 (North Carolina), SCN now infests all the major soybean producing states. The first infestation found in Illinois was in Pulaski County in 1959. To date, 98 Illinois counties have been confirmed with SCN infestations. Since the first find in the U.S., there has been much speculation concerning its introduction into major soybean producing areas. Although the proof is not absolute, there are some recorded facts and personal experiences that may shed some light on the introduction of SCN into the U.S. and once here, its spread to various geographical areas within this country.

Possible Spread of SCN to the U.S.A.

The first report of SCN was made by Hori in 1915 but a subsequent publication made in 1916 reported that "Moon Night Disease" (in reference to the pale yellow areas in fields) of soybean had been known in Japan for 30 years prior to Hori's publication. However, the nematode probably has a long association with soybean in Asia, but, unfortunately, translations of ancient Chinese literature have not clearly documented specific details of the disease. Lü Bu Wei, who died in 235 B.C., may have indicated the early presence of the nemotode in an early document concerning planting of soybeans to ensure plants with tall, thriving leaves, full pods, round seed, heavy seed weight, and tasty with no insects. The Chinese character used for insect at that time resembles the outline of a white cyst female with an attached egg mass. If the ancient Chinese observed white females on roots of soybean, they may have thought them to be insect larvae. These recordings, although not absolute, indicate a long association of SCN with soybeans in the Orient. But the question remains, "how was it introduced into the U.S.?"

Again, there were some early documents that shed some light on possible introductions from the Orient to the U.S. Reports in the 1800s described several importations of soybean seed from China and Japan and for that period of time, individuals involved did not document their activities in terms of today's requirements for importation of plant material. D. Fairchild, who organized the office of plant introduction in 1897, noted receiving collections of soybean seed from Japan and China obtained mostly from missionaries and consuls. It is possible that along with these seed shipments, soil containing SCN may have been present.

Of greater significance than the importation of seed as a means of introduction of the nematode into the U.S., was the importation of soil during the late 1800s from the Orient in order to obtain the nitrogen-fixing bacterium, *Bradyrhizobium japonicum*, for soybean inoculum. This bacterium is not native to North America. During the ensuing years, bacterium-infested soil was shared with various researchers for improving growth and health of soybean. As early as 1904, a publication recommended using 560 kg of soil per ha but stated that 110 kg would ensure nodulation. One of the most interesting articles was written by a man named Temple in 1916. He wrote "Naturally, as soon as it was learned that these bacteria were essential to the successful growing of legumes, men made efforts to ensure their presence, and this has led to the practice of seed and soil inoculation. This was first practiced by transferring soil from a field on which the particular legume to be inoculated has been successfully grown, and scattered it over the field to be planted—this

method gave excellent results, but it has serious drawbacks—it was heavy to apply, and was liable to carry noxious weed seeds, and troublesome plant maladies, such as cotton wilt, pea wilt, melon wilt, and nematodes." How true this statement may be, in terms of introducing and spreading the soybean cyst nematode to soybean producing areas of the U.S.

As mentioned previously, the soybean cyst nematode was first found in 1954 in North Carolina. This area of the state had a history of growing flower bulbs imported from Japan. Flower bulbs are not considered hosts of the nematode but perhaps soil that accompanied the bulbs was infested with the nematode. Although somewhat difficult to document, it is strongly suggested that soils from both China and Japan may have been the means of introducing the nematode into the U.S. In the early 1900s and prior to the use of the nitrogen-fixing bacterium, *Bradyrhizobium japonicum*, spreading of bacterium infested soil for soybean inoculation was common and this could account for the establishment of the nematode in various geographical areas of the U.S. where soybean production now occurs.

Possible Spread Within the U.S.

Infestations of the nematode discovered during the 1950s in North Carolina, Tennessee, Missouri, Arkansas, Mississippi, Illinois, Kentucky, and Virginia could have been due to infestations established many years ago as a result of soil and seed importations. The early infestations in the Midwest were concentrated along the Mississippi River from southern Illinois to northern Mississippi. The Mississippi valley area has long been known as major flyway for migrating birds. One southern Illinois cooperator found his first infestation in the middle of a field where migrating geese rested during their annual migration. A researcher in Tennessee found that cysts survived passage through the digestive system of birds. Long-range movement of the nematode in soil on farm machinery, in soil peds that accompany seed, and vegetable transplants have been documented by agriculturalists, including the author. A used combine purchased from a southern state and brought to southern Illinois contained viable (infective) soybean cyst nematodes. This was confirmed by the author in the late 1960s and movement of used farm equipment from this dealer had taken place for many years prior to this confirmation. A federal quarantine was established in 1957 to prevent the spread and dissemination of the nematode from infested areas to noninfested areas. It was determined to be ineffective and was rescinded in 1972 in part due to the assumed spread by migrating birds and the movement of soil on contaminated equipment and machinery.

Conclusions

There is strong evidence that the soybean cyst nematode may have been introduced into the U.S. several times during the late 1800s and early 1900s in seed lots and soil imported from the orient. The early importation of soil was for the purpose of obtaining bacteria to nodulate soybeans. The nematode was first found in the U.S. in North Carolina in 1954. Again, there is evidence that the nematode was introduced in soil surrounding flower bulbs imported from Japan. Once established in the U.S., the nematode spread rapidly to all soybean producing areas of the U.S. and now has been confirmed in twenty-nine states. Once established in geographical areas, the movement of soil infested with the nematode has occurred although documentation is not entirely clear. The nematode will continue to spread by any means that can transport soil from infested areas to noninfested areas. The awareness of this should be noted by soybean producers and sampling of fields should take place on a routine and timely basis. With the knowledge of the nematode presence, control strategies can be initiated to reduce losses caused by the nematode, now considered to be the most devastating pest of soybean.

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SOYBEAN SUDDEN DEATH SYNDROME: QUESTIONS AND ANSWERS

G.L. Hartman

Illinois often ranks number one among states in soybean [(*Glycine max* (L.) Merrill] production with >10 million acres planted in 1998. The production represents ≈16% of the total annual U.S. production. Soybean production is important in most counties in Illinois with the top 10 counties mostly located in the mid-section of the state (Anonymous 1997). Diseases often limit maximum yield potential. One disease, sudden death syndrome (SDS), has received more attention recently and has become a concern to Illinois soybean growers and commercial seed companies.

What is SDS?

In 1983, a soybean disease of unknown etiology was reported and named sudden death syndrome (Hirrel 1983). Disease symptoms include mottling, interveinal chlorosis and necrosis on the upper leaves at flowering and also root and crown rot, vascular discoloration of stems, defoliation and pod abortion (Hirrel 1983, Roy et al. 1989, Rupe 1989). The disease is caused by a soil-borne fungus that infects plant roots. Field patterns of SDS vary from strips or distinct patches to large, extensive patches that coalesce. The disease is normally seen on plants during the mid- to late reproductive growth stages often from mid- to late August.

How Important is SDS?

Initial yield loss estimates from greenhouse and microplots ranged from 10 to 77% (Roy et al. 1989). Yield losses from experimental plots in commercial fields ranged from 20 to 46% (Hartman et al. 1995) as diseased plants had fewer pods and seeds and less seed weight (Table 1). In addition, plants with SDS have poorer seed quality with lower germination rates and more seedborne pathogens than plants without SDS symptoms (Hartman et al. 1995). Because the disease intensity varies considerably from year to year due to environmental conditions, it may be the most important soybean disease one year and almost nonexistent another year. It is not possible to predict from year to year how important SDS will be in any given year, but wet soil conditions early in the growing season often result in greater symptoms later in the season.

Is the Disease Increasing in the State?

In soybean-disease-monitoring plots at 18 locations in Illinois from 1977 to 1987, in 1990, and in 1991, SDS was not ranked among 11 soybean diseases (Eathington et al. 1993). Although the disease has occurred infrequently for several years prior to 1993, it was not until 1993 that its occurrence was clearly documented in east central Illinois when SDS occurred in 46% of the soybean fields based on air and ground surveys (Table 2) (Hartman et al. 1995). In 1998, a statewide survey showed that SDS occurred in all agricultural statistics districts in Illinois with some districts having as high as 43% of the fields with at least some SDS (Table 2). There has not been a statewide survey to enumerate the pathogen that causes SDS, so it is not known if the pathogen is spreading or if changes in weather conditions, tillage patterns, varieties, or a combination of these or other factors have contributed to increases in SDS occurrence over the state.

Table 1 • Yields, seed weights and number of pods per plant from plants with four levels of sudden death syndrome (SDS) severity in a replicated experimental plot at Urbana, Illinois.[1]

SDS level[2]	Yield (kg/ha)	300 seed weight (g)	Seeds/stem segment (g)[3] upper	Seeds/stem segment (g)[3] lower	Pods/stem segment[3] upper	Pods/stem segment[3] lower
Low	2,441	47	181	178	24	21
Low-med.	2,011	43	135	111	17	18
Med.-high	1,634	38	116	108	20	18
High	1,439	37	89	72	15	16
LSD ($P < 0.05$)[4]	278	3	18	23	4	2

[1] From Hartman et al. (1995).

[2] Based on estimated visual ratings: low = 0 to 3% of the plants with SDS, low-medium = 4 to 25% of the plants with SDS, medium-high = 26 to 50% of the plants with SDS, and high = > 50% of the plants with SDS.

[3] Data represents pods or seeds in the lower or upper half of the plant.

[4] Least significant difference based on 4 replications.

What is Known About the Fungus?

The causal fungus is *Fusarium solani* f. sp. *glycine* (Roy 1997). The fungus produces blue-pigmented colonies on some media that can be enhanced with certain nutrients (Huang and Hartman 1996). It forms macroconidia and less frequently microconidia. Macroconidia germinate to form chlamydospores, thick-walled overseasoning structure of the fungus. Chlamydospores form within or adjacent to macroconidia in several ways and they form from germinated macroconidia and hyphae (Li et al. 1998a). Like many other species of *Fusarium*, *F. solani* f. sp. *glycines* produces toxins in pure culture or associated with plant tissues. Culture filtrates of the fungus were toxic to soybean calli, suspension cells, and plants (Jin et al. 1996a, Li et al. 1998b). A phytotoxic polypeptide with a molecular weight of 17 kD (Jin et al. 1996b) and the low-molecular-weight phytotoxin monorden (Baker and Nemic 1994) were identified in culture filtrates of *F. solani* f. sp. *glycines*. Neither of these toxins have been found in diseased plant tissue, although when stem-cuttings are immersed in sterile culture filtrate, SDS symptoms occur on leaves (Huang et al. 1998, Li et al. 1998b)

Is There Any Direct Interaction with SCN?

Several reports have studied the interaction of *F. solani* and *Heterodera glycines* (soybean cyst nematode [SCN]), the causal agent of soybean cyst. Dual inoculation with the 2 organisms caused increased SDS-foliar-symptom severity than with *F. solani* alone, although it was shown that SCN was not required for infection by *F. solani* in greenhouse (Roy et al. 1989) and microplot (McLean and Lawrence 1993) experiments. Soil samples taken from 25 fields in Champaign County from areas where all plants were showing SDS symptoms and in adjacent areas where plants appeared healthy did not differ in SCN counts based on cyst populations (Hartman et al. 1995).

What Management Options are Available?

There are several potential options for managing SDS. Selection of less susceptible varieties is one option. Soybean varieties and lines that exhibit various levels of foliar symptoms after being inoculated with *F. solani* f. sp. *glycines* have been reported, based on tests conducted in the growth chamber, greenhouse, microplots,

Table 2 • Occurrence of sudden death syndrome (SDS) in fields in east central Illinois in 1993 and by Illinois agricultural statistics districts in 1998.

Year	Area/district	Counties	Fields	Incidence (%)
1993[1]	East-central	5	409	46
1998[2]	Central	11	555	43
	East	7	630	40
	East-Southeast	15	694	21
	Northeast	11	134	28
	Northwest	12	182	17
	Southeast	12	427	24
	Southwest	12	352	32
	West	9	135	15
	West-Southwest	13	517	38

[1] From Hartman et al. (1995).

[2] Unpublished data resulting from a joint survey of the state between soybean researchers at Southern Illinois University and the Univeristy of Illinois at Urbana-Champaign.

and field. Researchers that develop commercial soybean varieties are aware of some of the differences in susceptibility among their varieties and soybean specialist at universities often provide test results of SDS screenings. Resistance to the pathogen was reported to be conditioned by a dominant gene (*Rfs*) in 'Ripley' (Stephens et al. 1993) and quantitatively in 'Forrest' (Hnetkovshy et al. 1996). In one study, >800 soybean plant introductions (PI), lines, and varieties were screened to obtain new sources of resistance (Hartman et al. 1997). One PI from China, PI 567.374, had lower foliar SDS severalties than PI 520.733, a resistant check, in both growth chamber and greenhouse tests. Because most of the commercial varieties are susceptibility, the PIs from China that exhibit low foliar SDS severity ratings may provide sources of resistance needed to develop new SDS resistant soybean breeding lines and varieties. In another study, fungal culture filtrates were used to show that foliar disease development on cut soybean seedlings immersed in culture filtrates and those from inoculated plants were positively correlated (Table 3), indicating that fungal filtrates may be another approach to evaluate host reaction to this disease (Huang and Hartman 1998).

Besides selecting less susceptible varieties, other methods of management may include practices that promote good root development. Although there is not enough research to substantiate that tillage influences disease, there are some indications that deep-ripping, at least in some soil types, will promote more extensive root development and less SDS. Other practices, such as treating seeds with fungicides and rotation, need further research to determine their affect on SDS. The best recommendation at this time is to plant less susceptible varieties.

Table 3 • Area under the disease progress curve (AUDPC) values of sudden death syndrome foliar-severity ratings for 5 soybean entries inoculated with *Fusarium solani* f. sp. *glycines* under greenhouse conditions for 21 d and for cut seedlings immersed in its culture filtrate under laboratory condition for 10 d.[1]

	Area under the disease progress curve	
Soybean entry	**Seedling**[2]	**Cut seedling**[3]
PI 567.374	68	109
PI 567.650B	118	193
PI 520.733	199	236
Great Lakes 3202	237	374
PI 567.659	366	410
LSD ($P = 0.01$)	159	86

[1] From Huang and Hartman (1998).

[2] Seedlings were inoculated in the greenhouse by using infested sorghum grain.

[3] Cut seedlings were immersed in diluted culture filtrate (50 water:1 culture filtrate) of *F. solani* f. sp. *glycines* under a 12-h photoperiod of fluorescent light at 25 ± 3°C in the laboratory.

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White Mold: Expectations for 1999

Wayne L. Pedersen and Glen L. Hartman

White mold has rapidly become one of the most important diseases of soybeans [*Glycine max* (L.) Merrill] in the North Central Region. It has been referred to as the "fuzzy fungus from the north" because the pathogen *Sclerotinia sclerotiorum* produces white, fluffy mycelia on the outside of the soybean stem that are diagnostic to this disease. White mold has been a severe problem for soybean growers in Iowa, Michigan, Wisconsin, Minnesota, and northern Illinois for several years; hence, it has been traditionally considered a disease of the northern soybean region. In 1994–1996, however, white mold was a severe problem in several areas of Illinois. The disease was present in 1997 but not at levels as severe as in 1996. The fields that had severe white mold in 1996 will again be planted with soybeans in 1998. Depending upon the weather in July and August in 1998, white mold has the potential to be severe.

In addition to the white, fluffy mycelia, the fungus also produces dark-black structures, approximately the size of rodent droppings, called sclerotia. These structures are specialized fungal resting bodies that enable the pathogen to survive for up to 5–7 yr in the soil. When soil conditions are moist, the sclerotia germinate and form small mushroom-shaped structures called apothecia. It is important that these small, delicate structures do not dry up, or they will not be able to produce the ascospores that are essential for infection. The denser the canopy, the more likely the apothecia will remain viable for several days, thereby producing more ascospores and a heightened potential for infection. The ascospores are discharged into the air and those that land on flowers germinate and infect. The fungus grows as the white, fluffy mycelium over the surface of the plant, killing the tissue as it obtains it nutrients. White mold has been more severe in drilled soybeans, primarily because the canopy is denser and the apothecia and the mycelia thrive in cool, moist environments. This disease also may cause more problems in soybeans with high yield potential because the crop has been planted early with a large population of plants. In warm, dry years, where 30-in. rows do not close the canopy, the apothecia tend to dry up before they discharge their ascospores; hence, the disease may not develop, but maximum yields are not reached. Unfortunately, white mold has become known as a disease of the best soybean farmers.

Genetic Resistance

Management practices can help reduce the level of infection, but they may not always provide adequate control of white mold. Studies have been conducted to evaluate host resistance. In 1997, we screened nearly 250 commercial cultivars and experimental soybean lines for resistance to white mold in the field and in the greenhouse. A summary of this evaluation is presented in Table 1. None of the cultivars was completely resistant to white mold, but several had partial resistance. If you have had problems with white mold in the past, we suggest you consult with your seed company to obtain the most resistant or tolerant cultivar with high yield potential.

Seed Transmission

It has recently been demonstrated that *S. sclerotiorum* can be seed transmitted. It has been known for many years that the pathogen can be moved as sclerotia mixed with the seed, but the role of infected seed has not been described. Seed infection was very evident in 1996 when seed samples were evaluated for warm germination on

Table 1 • Nearly 250 soybean cultivars were evaluated for resistance to white mold with natural field infection, inoculated field plots, and greenhouse inoculations in 1997.

Maturity group	Company	Cultivars
1.1–1.5	Dairyland Seed	DSR 158
	Limagrain	1831
1.6–1.9	DairylandSeed	D5R173
	Dairyland Seed	DSR 182 RR
	Garst	D163N (not SCN resistant)
	Garst	* D189
	Golden Harvest	H1174
	Hughes Seed	* 198
	Limagrain	CM 1750
	Novartis Seeds	S19-90
2.0–2.5	Dairyland Seed	DSR 220 STS
	Golden Harvest	H 1201
	Golden Harvest	H 1213
	Golden Harvest	H 1242 STS
	Hughes Seed	* 220X
	Sieben Hybrids	SS 2401 RR
	Sieben Hybrids	SS 2702 RR
2.6–2.9	Dairyland Seed	DSR 250 STS
	Golden Harvest	* H 1282
	Marlin Wilkin & Son Seeds	* 271
	Marlin Wilkin & Son Seeds	* 272 STS
	Marlin Wilkin & Son Seeds	* 291 CN
	Sieben Hybrids	* SS 291
	Public (Illinois)	Iroquois
	Public (Illinois)	* Jack
3.0–3.9	Garst Seeds	* D308
	Golden Harvest	H 1322
	Marlin Wilkin & Son Seeds	* 301C
	Pioneer Hi-Bred Int.	9381
	Sieben Hybrids	* SS 326

The 30 most resistant varieties from the test are listed. None of the varieties was completely resistant; therefore, it is recognized that any or all of the varieties may and probably will have white mold under high disease pressure. This research was supported by Illinois Soybean Check-off Research Funding.

*These varieties had yields that exceeded 55 bu/acre at Watseka, IL.

blotters. In several seed lots, the characteristic white mycelium and sclerotia were produced from normal seed. Without the characteristic sclerotia, infected seeds may resemble seeds infected with *Phomopsis longicolla, Diaporthe phaseolorum,* or both (Phomopsis seed decay). The level of infection was fairly low, usually <2%. The infected seeds did not germinate, hence seedling infection does not appear to be important. The development of sclerotia on the blotters, however, indicates that infected seed may be a possible means to introduce the pathogen into new fields. In 1997 and

Table 2 • The number of sclerotia, apothecia, and stipes formed from 500 infected soybean seeds in 1997 and 1998 under field conditions.

Year	Sclerotia	Stipes	Apothecia
1997	553	20	10
1998	201	22	0

Stipes are small stalks that are produced during germination of the sclerotia and apothecia (small mushroomlike structures) are formed at the tip of a stipe.

1998, we designed a study to determine if infected seeds could produce sclerotia and apothecia. Results of that study demonstrate that the infected seeds do produce sclerotia and the sclerotia produce apothecia in the field Table 2).

What does this mean to the grower? First, *S. sclerotiorum* has a very wide host range and infects many broadleaf weeds. In addition, the sclerotia can survive in the soil for up to 5 yr. Although the importance of seed infection has not been determined experimentally, it potentially may be a mechanism for the fungus to spread into new fields. Second, if seed is saved from infected plants, it is important to have the seed cleaned and sized to remove sclerotia and small infected seeds. To determine if a seed lot is infected, it is essential to have a germination test done and ask if white mold was observed. Illinois Crop Improvement is currently doing this test. Third, if an infected seed lot is to be used for seed, a fungicide seed treatment will control the infection (Table 3).

In conclusion, white mold is a disease that can cause severe yield reductions if the inoculum is present and the weather is rainy or foggy in July and August. The incidence of white mold can be reduced with crop rotation and row spacing, but the most effective and economical means of control will be through genetic resistance.

Table 3 • Effectiveness of flingicide seed treatments in reducing seed transmission of white mold.

	Total sclerotia	
Treatment	1997	1998
Control	324	150
Maxim	1	7
Rival	0	3
Thiram	1	8
TBZ	Not tested	27

Total sclerotia produced from 160 infected seeds.

PRECISION AGRICULTURE—DOES IT PAY?

Don Bullock

The introduction of precision technology into production agriculture has been accomplished. There is little doubt that the equipment can do most of what we want it to do and many reasonable arguments can be made as to the merits of the agronomic advantages. The simple fact is that much of what we call precision agriculture indeed does work. One major question, however, that needs to be answered is, Does it pay? Can we expect an increase in revenues or a decrease in costs large enough to compensate for the cost of the precision agriculture technology and services? The answer to that critical question is not simple. I suggest that the answer depends on the type of problem the technology is addressing. For some problems precision agriculture will pay, but it is also clear that precision agriculture is not appropriate for all of the problems we face. This paper presents some of the variable rate seeding research that has been completed at the University of Illinois (Bullock et al. 1998). Although much of the following text outlines an area in which precision agriculture does not pay, it should not be construed as a general statement or opinion as to the relative worth of precision agriculture, but rather as a cautionary note for all of us to "look before we leap."

Variable Rate Seeding of Corn

Not all fields nor even portions of fields have the same economically optimal corn (*Zea mays* L.) plant density. In any seeded section of a field there is competition between plants for resources. Generally, field sections characterized by relatively limited resources, such as water or essential elements and minerals, have relatively low yield potential and are suggested to be of lower quality. Conventional wisdom states that lower-quality field sections also have lower economically optimal plant densities than higher-quality sections, although basic economic theory shows this need not be the case. The existence of such a correlation between economically optimal plant density and field-section characteristics is necessary for variable rate seeding (VRS) of corn to be profitable to the farmer. Without a correlation, all field sections, regardless of yield potential, would have a similar economically optimal plant density, and VRS would not be profitable for the farmer. So, knowledge about the magnitude of the correlation between field-section quality and economically optimal plant densities is of significant practical importance. Unfortunately, very little research on this topic has been conducted. The objective of field research discussed in this paper was to provide an estimate of the economic value, to the farmer, of VRS technology. This objective required that an estimate of the correlation between field quality and economically optimal plant density of corn in the central Corn Belt.

To determine this correlation, we obtained a large data set from Pioneer Hi-Bred International, Inc., that we have designated as the Pioneer data set (PDS). The PDS consists of >42,000 individual experimental unit observations from small-plot research conducted by the Agronomy Sciences group at Pioneer during 1987–1996 in Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin. Treatments consisted of final hand-thinned stands of 18,000 to 42,000 plants per acre. The PDS constitutes 170 site-years. No site (i.e., exact position within a given field) was used more than once in the PDS and thus the 170 site-years is appropriately considered 170 unique sites. Hybrids varied widely and consisted mainly of Pioneer-brand hybrids but also included the majority of the other commercial hybrids used during this study. As described by Bullock and Bullock (1994), economically optimal plant densities

were determined based upon a quadratic functional form and a \$1.25 per 1,000 seed cost and a \$2.50 per bushel grain value. Yields were adjusted for both technology and weather. Site quality (roughly designated as yield ability of a site) ranged from 80 to 280 bu/acre for the 170 sites in the data set. The site-specific economically optimal plant densities ranged from ≈18,000 to 42,000 plants per acre.

Simple linear correlation analysis of the site-specific economically optimal plant densities upon site qualities provided a Pearson correlation coefficient of 0.27 ($P > |R| = 0.0002$). Thus, site quality is not a good predictor of economically optimal plant density. This outcome is critical because a farmer has to make a map to drive a variable rate planter and most farmers believe that they will be able to use a long period of yield maps to discover the yielding ability of their field sections and then work under the additional assumption that the higher-yielding areas require more seed. A correlation coefficient of 0.27 indicates that approach is not going to work very well. The plain fact is that different areas of fields have different economically optimal final stands, but the final level is determined by many factors other than yield potential.

We also found that there is very little difference in the economically optimal plant densities of most fields as shown in equation [1].

$$\text{Economically Optimal Final Stand} = 21{,}900 + 32^{*}(\text{site quality in bu/acre}) \qquad [1]$$

For every 1 bu/acre increase in site quality, the predicted value of the site-specific economically optimal plant density increased by only 32 plants per acre. Although statistically significant, 32 is a relatively modest slope. Equation [1] also predicts that even relatively modest site quality requires a substantial plant density. For example, a site with a quality of 125 bu/A is predicted to require ≈25,900 plants per acre, whereas a site with a quality of 175 bu/A is predicted to require ≈27,500 plants per acre. This difference of 1,600 seeds per acre is less than the amount most farmers overplant to compensate for nonuniform germination and emergence. It is also critical to realize that equation [1] indicates there is considerable down-side risk to not having sufficient seed in field sections of relatively modest quality; even lower-yielding areas of fields require relatively high final stands.

To finish this work we created a simulated field of 170 sections of uniform size based on the actual data set. This design allowed us to assume that we really did know the relationship between grain yield and final stand for each section of our simulated field. The reality is that no farmer can afford this sort of detailed information, so we compared it with what farmers probably do know—a detailed yield history. We then repeated our simulation under 2 scenarios. (Actually we used 4 scenarios, but for sake of space only 2 of them are presented here. For a more complete discussion, see Bullock et al. (1998)). In the 1st scenario we assumed that the farmer of the simulated field has the ability to seed at a variable rate and knows the true yield response function for every one of the 170 sections. With this knowledge and technology he or she can calculate from equation [1] the specific economically optimal plant density for every site. This 1st scenario is called the "full information variable rate seeding scenario."

In the 2nd scenario, the farmer of the simulated field also has the ability to use VRS, as he or she did in scenario 1, but the actual yield response function for any section is not known. For each of the 170 sections, however, the section's quality, which again can be thought of as the yield ability of that section, is known. This scenario reflects a situation in which over a period of time the farmer has accumulated an extensive series of yield maps via a combine yield monitor with global positioning system (GPS) capabilities. Thus, the farmer has a good idea about each section's yield history and a reasonable proxy for the quality of each section. Note that in this scenario the farmer is working with only partial information for each section and that limited information constraint, generally establishes a plant density that is economically inferior to that of the farmer in the 1st scenario who uses VRS and possesses full information. We called this 2nd scenario the "partial information variable rate seeding scenario."

Comparisons of per-acre revenues minus seed costs across the scenarios were conducted to estimate the economic benefit of VRS and knowing the yield response functions for the simulated field. The profit one realizes from VRS will be, by definition, equal to the change in revenues minus costs. The change-in-revenues portion of this calculation is simply the change in yield times grain price. The cost changes include changes in seed costs and increased costs for VRS equipment and services. Currently, it is difficult to provide an exact cost for VRS equipment and services so they were not specifically included in our calculation, but will be addressed generally in our discussion.

Neglecting the costs of VRS equipment and services, under full information the farmer of the simulated field can increase revenues minus seed costs by \$5.19/A by using VRS instead of uniform seeding of the entire simulated field. So, if the costs of VRS are less than \$5.19/A, and if the farmer has full knowledge about how yield responds to plant density on each section of his or her field, then profits could be increased by using VRS.

In this 1st scenario, however, we are assuming that a farmer knows the true production function for each section, but the reality is that no farmer will know that much. The value of \$5.19/A is the best that a farmer could expect with perfect knowledge and no farmer has perfect knowledge. This leads us to the more realistic 2nd scenario.

We calculated profit on the simulated field under the partial information, variable rate seeding scenario. Neglecting the costs of VRS equipment and services, under partial information the farmer of the simulated field can increase revenues minus seed costs by a trivial \$0.22/A by using VRS instead of uniform rate seeding. This outcome indicates that the value of knowing the yield response to plant density for each section accounts for \$4.97/A (\$5.19/A – \$0.22/A) or virtually all of the profit.

The 1st major finding of this research is that VRS will only be profitable to the farmer who knows a lot about the relationship between yield and plant density for each section of a field. This is far more knowledge than any farmer currently possesses. There are 2 ways by which such knowledge may be gained. First, a series of agronomic experiments could be run in each section of a farmer's fields over a period of many years to obtain a reasonable estimate of the response of yield to plant density in each section. This daunting task would require the farmer to overlay each field section with a series of small plots, assign differing plant densities to each of the plots randomly, obtain yield measures from each plot, record stochastic variables (e.g., weather), and estimate a response function for each section of the field to estimate an economically optimal plant density for each section. It is obvious that such an endeavor would be extremely complicated and prohibitively expensive for an individual farmer.

Alternatively, the research community could generate and provide to the public detailed information indicating which field characteristics (e.g., soil texture, slope, and organic matter) are important and how they affect the relationship between grain yield and plant density. Although scientific literature recognizes that economically optimal plant densities differ among field sections predominately because characteristics vary among field sections, little is known about how specific characteristics affect the economically optimal plant density. Gaining knowledge of the specific relationship between characteristics and yield response to plant density would require massive research efforts over many years and locations. Only a small part of this work has been completed. The ultimate product of this research would be a multivariate function that estimates the response of yield to input application rates, site characteristics, and weather. Even if such a response function were precisely estimated, each farmer would still have to measure the appropriate characteristics in each section of each field to understand how plant density affects yield in each section. For any farmer, measuring the characteristics in every section would be expensive because the list of pertinent characteristics may be long, the work required to obtain estimates of these characteristics in any section is likely to be great, and the number of sections with differing characteristics is sure to be large.

Our 2nd major result is that without VRS technology, information about yield response to plant density in every section is of very little value to the farmer. Thus, we conclude that VRS technology and information about yield response in every section are highly complementary; a farmer has no incentive to adopt the new technology without the information necessary to make it economically viable, and a farmer has no incentive to acquire the information unless VRS technology is available.

The sticking point, and the major conclusion of this work, is that although much attention has been given to the future possibilities of VRS in the popular press, this technology on its own is of no economic benefit to farmers with our currently limited knowledge of the effects of characteristics on yield response. If VRS is ever to be profitable on a large scale and adopted, farmers need to know much more about how the characteristics of their fields' sections vary, and how this variability causes yield response to plant densities to vary across sections. Our results show that although economically optimal plant densities and field quality are correlated, simply possessing vague knowledge about the quality of a field's sections—this is the type of knowledge currently being promised to farmers by companies selling yield monitoring and GIS technology—will not suffice to make VRS economically beneficial to farmers. Farmers have to possess precise and appropriate guidance maps to direct corn planters if they hope to benefit from VRS. Given current limitations to our knowledge about field characteristics and yield response, such maps cannot be made.

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SPLIT-PLANTER COMPARISONS: AN INDUSTRY PERSPECTIVE

Lou Chapko and Tom Doerge

The split-planter comparison method is a new precision farming tool that helps evaluate the performance of 2 agronomic treatments across whole fields. This method can help commercial producers use their yield monitors to make sense of the many new crop inputs and farming practices available. With the ability to continuously capture virtually every piece of yield data throughout a field with a yield monitor, commercial producers can now make meaningful comparisons across whole fields in a way that was not possible to do with side-by-side data alone. A common split-planter design is to compare 2 different hybrids or varieties. The planter is split with seed supplied from one hybrid or variety on the left side to be compared with a different hybrid or variety on the right side. The field is planted in a typical serpentine pattern resulting in alternating strips of the 2 hybrids or varieties across the field. The split-planter method also could be used to compare seeding rates, tillage treatments, pesticide selections, nutrient applications, or any number of paired agronomic treatments.

Designing Split-Planter Comparisons

The split-planter comparison method can be used to evaluate any two agronomic treatments in parallel strips. Some common examples of comparisons include:

- Standard versus newer hybrids or varieties.
- Hybrids or varieties from different seed companies.
- Two seeding rates, ground speeds, or seed treatments.
- Two fertilizer treatments, such as starter versus no-starter.
- Two tillage treatments if tillage and harvest equipment widths are compatible.
- Two pesticide treatments or herbicide resistance traits, if application and harvest equipment widths are compatible.

When hybrids or varieties are tested, they should be within 5 d relative maturity, 5% grain moisture content at harvest, and 5 lb/bu test weight. These conditions reduce the chances that the 2 cultivars will need different calibrations of the yield monitor.

Establishing a Split-Planter Comparison

Establishing a split-planter comparison may be as simple as placing a different product in each half of the planter. Planting the field normally results in pairs of adjacent hybrid strips across the whole field, as shown in Figure 1. The 2 hybrids should be randomly assigned

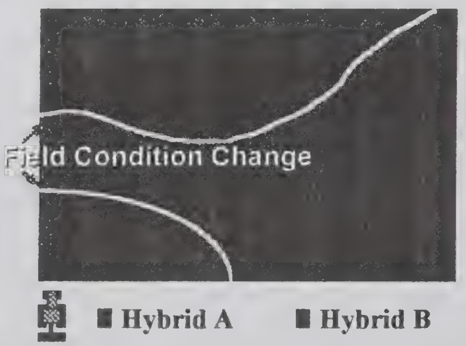

Figure 1 • Field layout of split-planter comparison of 2 hybrids.

to the right and left halves of the planter. Take care to ensure that the seeding rate and planter adjustments are appropriate to achieve the same stand of each hybrid or variety on both sides of the planter. Care must be taken to avoid switching the products each time the planter boxes are filled. In addition, an accurate record must be kept of where each product was planted.

Harvesting and Collecting Split-Planter Data

For best results, the width of the combine harvest header should be exactly one-half of the planter width. Data from a split-planter comparison should be collected with a yield monitor that is equipped with a differential global positioning system (DGPS) receiver. Use of a weigh wagon or scale is recommended to help ensure the proper calibration and function of the yield monitor.

It is critical that the grain harvested from the 2 hybrids (or treatments) be identified and harvested correctly (Figure 2). Using the *Load* or *Variety* feature on the yield monitor display is an easy way to differentiate the 2 hybrids or treatments. As the combine alternates between hybrid strips, the operator simply changes the load on the yield monitor to reflect the hybrid being harvested. For example, all even-numbered loads could be Hybrid A and all odd-numbered loads could be "Hybrid B." Another way to differentiate the 2 hybrids is to enter the hybrid name after the load number. For example: L1: 3489 L2: 34R07, etc. A detailed planting map or plan should be in the combine at all times when a split-planter comparison is being harvested.

When possible, the adjacent strips of the 2 hybrids or treatments should be harvested while traveling in the same direction, particularly in sloping fields. Yield data should be collected every second if possible.

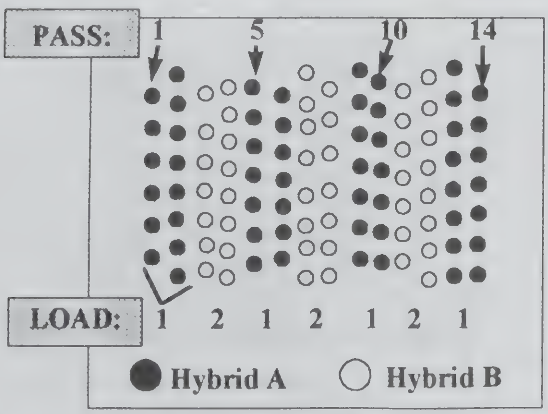

Figure 2 • Typical harvest pattern. Combine makes two passes per hybrid strip and assigns harvest data to Load 1 or Load 2.

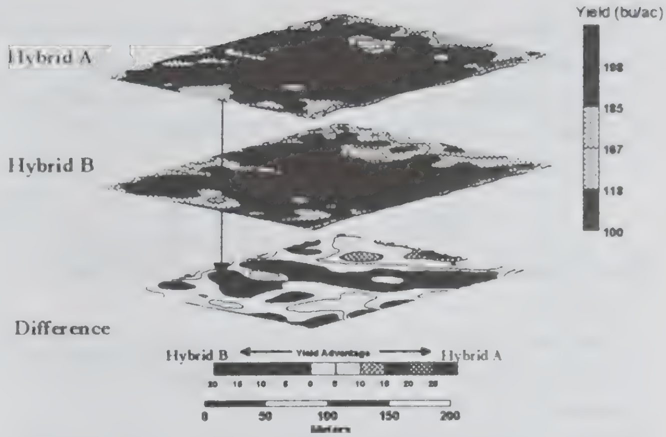

Figure 3 • Overlaying two yield surfaces to create a difference map.

Creating the Yield Difference Map

There are several options available to create a yield difference map—through a Pioneer representative, existing geographic information system (GIS) software or new software products just being released.

Figure 3 shows an example of the process used to create a yield difference map. The general process includes creating a separate yield map for each hybrid as if it were planted across the entire field, and overlaying these 2 maps and calculating the yield difference over the entire field.

A more detailed description of the difference mapping process is outlined in the following steps:

1. The first step is to inspect the yield data file and search for outliers. Outliers are points that reflect erroneous yield values or that have latitude and longitude coordinates located outside of the field boundaries. If any clean up of the data is needed, it should be done before any manipulations of the data are made.
2. The analysis process involves looking at the data for each hybrid separately and rasterizing a yield grid for each. Rasterizing is an operation that converts point data to grid cell values. Typically, a 50 by 50-ft grid is used. By converting the data to a raster format, mathematical comparisons or operations between 2 or more layers can be performed.
3. When the comparison process begins, an analysis window moves around the grid. For each grid cell location, the average yield values of the 2 hybrids

are compared and the resulting difference value is assigned to the corresponding grid cell on the difference map. The result is a map of yield difference values that represent yield advantage trends across the field (Figure 4).

Interpreting the Yield Difference Map

As with regular yield maps, difference maps often generate many new questions. The challenge is to correlate yield difference patterns on the map with specific environmental or field conditions that had the most direct effects on crop yield. These conditions will vary from field to field and year to year and include such factors as climate, soil type, slope, plant population, and aspect and soil nutrient status. Ideally, the features that cause different yield performance between the 2 hybrids or treatments will be consistent from year to year. If so, the grower may decide to switch to a different hybrid or practice in future seasons based on the yield difference map. Another scenario might be to plant more than one hybrid or variety within a spatially variable field. For example, the grower may decide to plant a drought-resistant hybrid only in the moisture-stressed portions of a field, and a different hybrid in the higher-yielding portions of the field to increase overall field productivity.

Figure 5 shows an example from a farm in Illinois where 2 hybrids show a differential response depending on the location in the field. In one part of the field Hybrid A has a 10.2 bu advantage over Hybrid B, but in another part of the field the performance is reversed.

The key issue is to investigate why there is a difference in performance between the 2 hybrids and to determine if this difference is likely to be repeatable from year to year. In this example there was a soil type and topography change that affected relative yield performance.

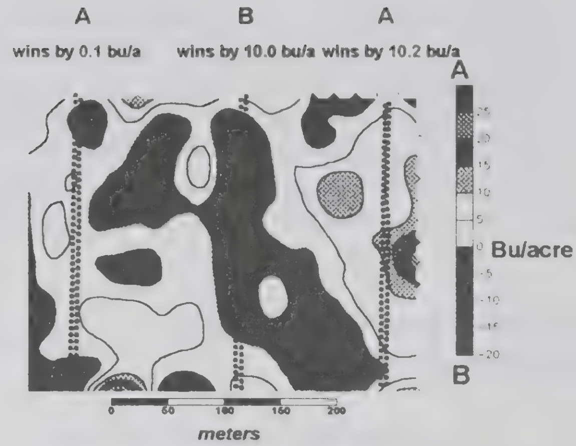

Figure 5 • Evaluating side by side comparisons.

The yield map in Figure 6 captures critical spatial information that shows the relationship between yield and differences in topography and soil types within the field. The yield difference map shown in Figure 4 also shows these same spatial patterns in this field. Namely, the lower-yielding eastern portion favored Hybrid A and the higher-yielding broad-hilltop feature in the center of the field is where Hybrid B performed the best.

The ability to bring a yield difference map into a GIS and overlay it with other spatial data layers greatly increases the value of the map as a crop management tool. In addition, a GIS allows the user to explore the data more completely and generate new information. These spatial queries could include evaluation of profit, yield variability, and yield stability within a field. Evaluating yield difference maps of the same or similar treatment comparisons over several years, locations, or both also will increase the level of confidence in management changes based on yield difference maps.

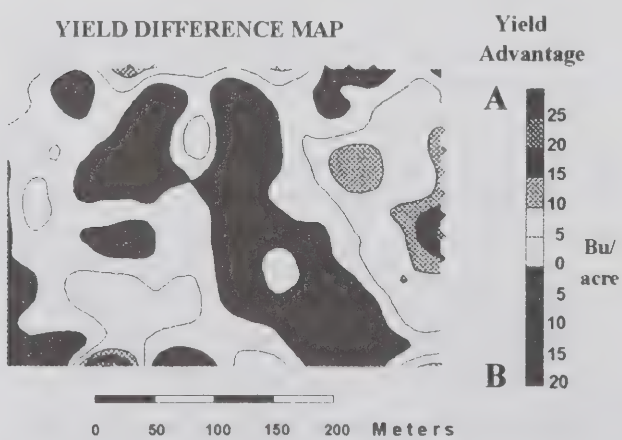

Figure 4 • Yield difference map.

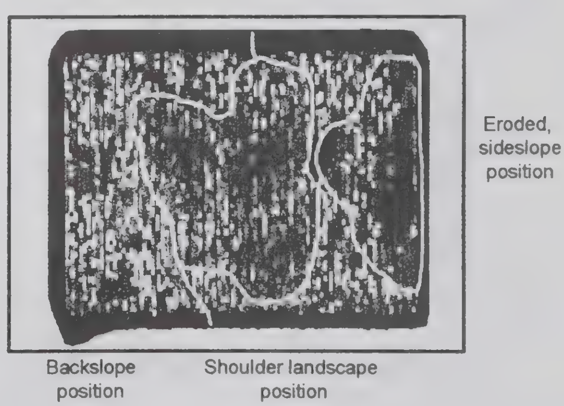

Figure 5 • Capture spatial information.

A DISCUSSION OF VARIABLE RATE N APPLICATION

Patrick D. Harrington, Emerson D. Nafziger, and Robert G. Hoeft

The adoption of precision farming technology by producers has increased the interest in managing inputs on a site-specific as opposed to a whole-field basis. The use of yield monitors has demonstrated the magnitude of yield variability within a field. This variability may indicate different requirements for nitrogen (N) fertilizer in different parts of a field. If so, N applications made on a site-specific basis should improve the efficiency of N fertilizer use.

The first step in developing site-specific N recommendations is to determine what factors can be used to adjust current N recommendations for a specific site. A yield monitor can be a valuable tool to evaluate N response within a field. Contrary to the widespread practice of recommending N rates based on anticipated yield, Davis et al. (1996) noted that yields of crops grown under high N fertilizer rates may not be useful indicators of N requirements. Carr et al. (1991) found that soil type predicted yield level, but that variable-rate application of fertilizer by soil type did little to improve economic returns to fertilizer. Snyder et al. (1996), in contrast, showed an average return of ≈$14.00 per acre in irrigated corn (*Zea mays* L.) when N rates were adjusted for yield goal, soil nitrate content, and soil texture.

Table 1 • Cooperators participating in site-specific N application trials in central Illinois.

Cooperator	County
Adams, John	Logan
Corzine, Leon	Christian
Dalenberg, Ken	Piatt
Harford, Doug	Grundy
Hunt, Andy	Grundy
Johnson, Mick	Morgan
Reifsteck, John	Champaign
Sasse, Dean	Dewitt
Sauder, Ken	Tazewell
Western, Kent	Morgan

The objective of this study was to examine N responses as measured by yield monitors from field-scale N rate strips in farmers' fields, and to use these responses along with soil type maps to see whether or not optimum N rates vary sufficiently within fields to support the use of site-specific N applications.

Materials and Methods

A trial was conducted at 20 site-years in central Illinois from 1995 to 1997. Over the 3 yrs of this study, 10 farmers participated, with trial locations in 8 counties. Cooperators were selected based on their interest, experience in operating combine-mounted yield monitors, and availability of accurate N fertilizer application equipment. A list of cooperators and counties in which they are located is given in Table 1.

Field-length strips, ranging from 15 to 40 ft. in width and 250 to 2,500 ft. in length were established using different rates of sidedressed N fertilizer (usually anhydrous ammonia) at each site. Two or 3 replications were made at each site. Yield data were collected by each participating farmer, using their own yield monitors equipped with global positioning receivers and differential correction systems to obtain field position. Each of the N rate strips in the trial was assigned as a "load" on the yield monitor to simplify identification of the strips.

The geographical information system (GIS) programs ArcView 3.0a (ESRI 1997), Green Plan Analyst (Milby 1997), and Ag Link 3.51 (Agris 1995) were used to analyze the yield data. Yield data were filtered and outliers were removed. Data were extracted and analyzed from areas within each field representing different

soil types and different yield levels. Data points were designated as low-yield if they were less than the mean yield minus one-half of a standard deviation, and as high-yield if they exceeded the mean plus one-half of a standard deviation calculated from all of the data in that field. To avoid assigning low-N-rate strips as low-yield areas, yield levels in low-N strips were adjusted by adding to each data point in those strips the difference between the yield under optimum N rates and those under reduced N rates, calculated over the entire trial. Soil types were identified from digitized Soil Conservation Service maps. Responses to N were calculated on the basis of all data from a particular yield level or soil type.

The quadratic-plateau model was used to develop an N response curve for each site, for the different soil types, and for areas of differing yield level. The economically optimum N rate was calculated from these curves based upon an N cost of $0.20/lb and a corn (*Zea mays* L.) price of $2.60/bu.

Results and Discussion

Of the 20 sites in this study, 16 were responsive to N fertilizer. The optimum N rates, estimated from all yield data from each site, ranged from the base rates of 60 to 77 lb of N/A at the nonresponsive sites to the highest rate of 210 lb of N/A at a site (Sasse in 1996) where the calculated optimum N rate exceeded the maximum applied rate (Table 2). These responses are typical of those noted in other series of N-rate trials conducted in recent years in Illinois.

Although nonresponsiveness to N rate is not uncommon in trials such as these (Brown in 1996), such sites weigh considerably against the feasibility of variable-rate N application, and a way to predict such occurrences would be very useful. In our study, trials in the fields of one producer (Table 2, Sauder) showed no response to N rate in all 3 yrs, with the trial in a different field each year. This producer uses some planter-applied starter fertilizer, as well as some N solution as herbicide carrier, prior to application of most of the N after crop emergence. He responded to the findings of this trial by reducing the rate of sidedress N after the first 2 yrs of the study. The other nonresponding site (Table 2, Western in 1996) was characterized by stand problems and much variability.

Although the optimum N rate appeared to vary with optimum yield level among the responding sites, the regression of optimum N rate on optimum yield was not significant ($R^2 = +0.39$). The correlation coefficient was 0.56, indicating that raising the yield by 1 bu should raise the amount of required N by 0.56 lb of N/A. Still, significant outlier points (Table 2;. Johnson in 1996, when 60 lb of N produced 186 bu of corn, and Johnson site in 1997, when it took 179 lb of N to produce 143 bu) are cause for concern about the reliability of applying N according to (differing) expected yields in a field. Such inconsistencies appeared in a number of locations and in each year.

Examination of yield responses to N rate by soil type (data not shown) did little to improve the correlation between optimum yield and optimum N rate. Nearly all of the fields used in these trials included soil types that differed in expected yield by ≤30 bu/A, so the fields tested were not extremely variable. If different soil types in the same field called for optimum N rates to differ by 30 to 40 lb/acre, however, actual differences in both optimum N rates and optimum yields were generally less than expected. At one site (Table 2, Hunt in 1995), soil types rated at 91 and 138 bu/A, respectively, produced optimum yields of 121 and 122 bu/A, at optimum N rates of 134 and 134 lb of N/A, respectively.

Using actual yield level to predict optimum N rate did little to improve accuracy of prediction. As with whole-field data, low-yield areas of fields generally required less N than high-yield areas (Table 2). There were some prominent exceptions, however, to this trend. At the Hunt site in 1995, the maximum rate of N applied (233 lb of N/A) was needed to produce 100 bu/A of corn in the low-yield portion, whereas 129 lb of N/A produced 134 bu/A in the high-yield areas (Table 2). Of the 14 sites at which sufficient response could be defined in both low-yield and high-yield portions of the field, 7 sites had higher optimum N rates in the low-yield portion of the field than in the high-yield portion.

With the availability of equipment, it is likely that the practice of variable-rate application of N will continue to expand, even though results such as those reported herein provide little general support for the concept. A great deal of additional work must be done by agronomists and farmers to adapt this practice to individual fields. One way this goal might be accomplished is through the use of long-term yield data that should prove better at predicting yields than soil type or short-term data. The use of alternating variable-rate strips with uniform-application strips also will be a valuable tool to evaluate and fine-tune this practice.

Table 2 • Optimum N rates and yields at optimum N rates calculated from all data, and from low- and high-yield data, at each on-farm site in Illinois, 1995–1997.

		All data		Low-yield data		High-yield data	
Cooperator	Year	Opt. N rate lb N/acre	Yield bu/acre	Opt. N rate lb N/acre	Yield bu/acre	Opt. N rate lb N/acre	Yield bu/acre
Adams	1995	76	112	79	83	78	132
Dalenberg	1995	124	140	66	116	120	151
Hunt	1995	120	121	233	100	129	134
Johnson	1995	122	166	97	128	132	183
Reifsteck	1995	141	114	66	86	144	129
Sauder	1995	66*	135				
Adams	1996	104	138	74	116	130	154
Harford	1996	127	127	133	112	127	146
Hunt	1996	99	135	125	100	97	157
Johnson	1996	60	186	**		**	
Sasse	1996	210	213	**		**	
Reifsteck	1996	119	142	113	124	136	161
Sauder	1996	77*	148				
Western	1996	60*	130				
Corzine	1997	174	165	194	146	188	179
Johnson	1997	179	143	146	114	198	163
Reifsteck	1997	146	153	134	138	143	163
Sasse	1997	103	130	107	113	105	144
Sauder	1997	76*	123				
Western	1997	140	140	146	122	138	153

*Yield response to N rate was not significant; lowest N rate and yield at that N rate given.

**Insufficient separation of low- and high-yielding data to allow analysis by yield level.

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NITROGEN BALANCE IN ILLINOIS: RECOMMENDATIONS FOR 1999

Bob Hoeft

Nitrogen (N) and phosphorus (P) are required for plants and animals to attain normal growth and development. Although the need for supplemental fertilization of these nutrients has been well documented, it is only in the last 2 or 3 decades that risk to the environment associated with improper application of these nutrients has been recognized. Nitrate levels above the U.S. Public Health standard were observed in surface waters in Illinois over 30 yr ago. More recently, an increase in the hypoxia zone in the Gulf of Mexico was attributed to an increase in N and P loading of the Mississippi River. In an attempt to ascertain factors that might be causing this increased loading, we prepared a total N and P budget for Illinois for the years 1970–1996.

Although both N and P are needed on Illinois soils, the history of when supplemental fertilization of these 2 elements was started is different. Farmers recognized early in the 20th century that most Illinois soils could not supply adequate P for crop growth, and as a result they began to fertilize with rock phosphate. Following World War II, P fertilization programs shifted from rock to acidulated phosphate materials. Fertilization programs throughout the century have built P soil test levels to the point where soils can now support optimum yield, but to maintain optimum yields on most fields, P fertilizer needs to be added to replace the P being removed in the harvested portion of the crop.

Relatively low grain yields, crop rotations that included forage legumes for 1 or 2 yr ahead of grain crops, and the natural release of N from soils accounted why supplemental N fertilizer was not needed in the early part of the 20th century. Starting in the mid 1950s, however, as grain yields increased and rotations shifted from corn–wheat–clover to corn–soybean, the need for supplemental N fertilizer increased. Today, there are few soils in Illinois that can support or maintain optimum corn grain yield without supplemental N and P fertilization.

Nitrogen Input

The significant N sources in decreasing order of the magnitude of their contribution are mineralization from soil organic matter, fertilizers, legumes, atmosphere deposition, livestock waste, and human waste

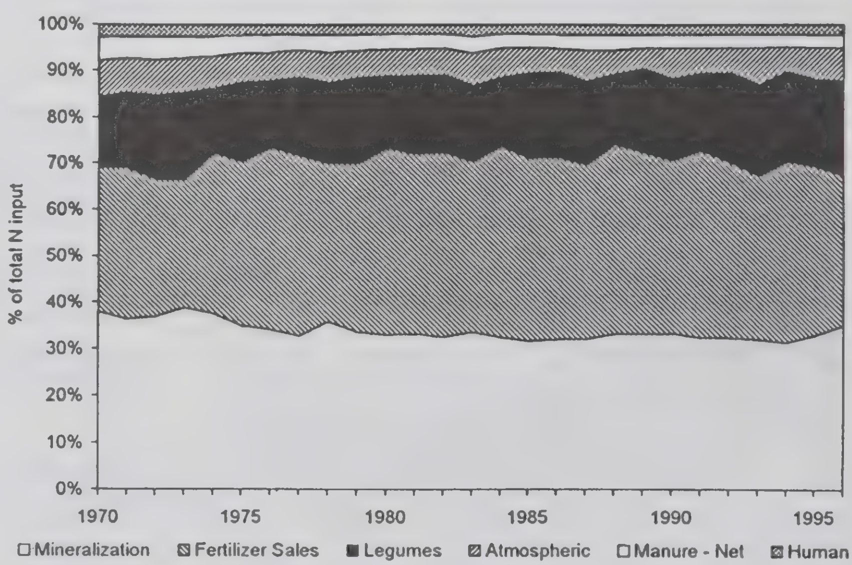

Figure 1 • Relative contribution of N input sources

(Figure 1). Except for mineralization, reasonable estimates of the magnitude of contribution of each source can be derived from statistics available from the Crop Reporting Service, the Census Bureau, and the National Acid Deposition Program.

Figure 2 • Illinois N fertilizer sales

Mineralization is the process where N in soil organic matter is converted to inorganic (plant-available) N by soil microorganisms. On average, 20 lb of N will be released per acre for each 1% of organic matter present in the soil. For this estimate, we used harvested cropland acreage—pasture land was not included—and assumed an average organic matter level of 3.5%. Although cropland acreage is well documented by the Illinois Crop Reporting Service, the average organic matter content of Illinois soils is not known with certainty. Because mineralization is a biological process, the rate of reaction is dependent on soil temperature. We recognize that it is not consistent from year to year as shown in the estimate, but there is no model that will predict accurately the precise rate.

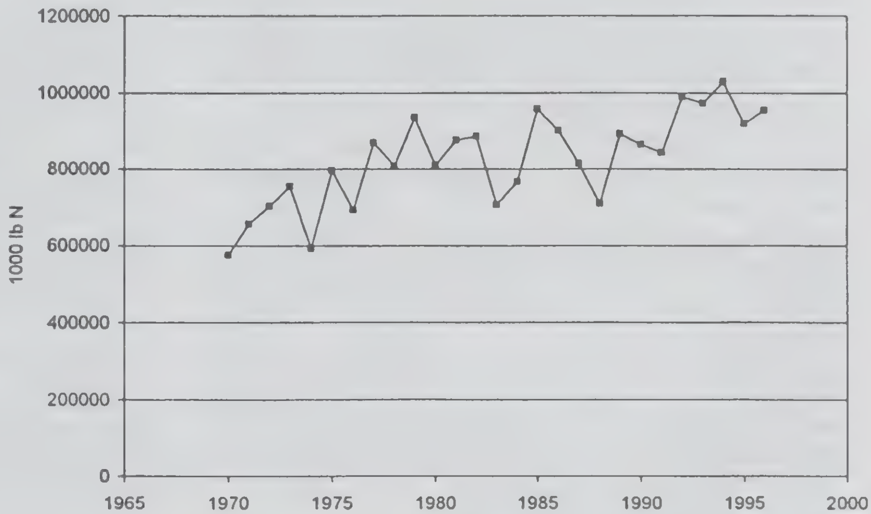

Figure 3 • Net N contribution from legumes in Illinois

Illinois farmers used just over a 0.5 million ton of fertilizer N in 1970. This use increased to over 1 million tons by 1980 and continued at that level until 1985 when it decreased. Use currently appears to be relatively constant at ≈0.8–0.9 million tons (Figure 2). The rapid increase in consumption through the 1970s and into the early 1980s was spurred by high grain prices. The marked decrease in consumption in 1983 was brought about by the Payment in Kind (PIK) government program that idled significant acreage. Several factors contributed to the decrease or leveling off of N consumption in the late 1980s and 1990s. These factors included an extended drought in the late 1980s that reduced farm income and also allowed producers to credit some carryover of N from the previous low crop yields; higher N prices; new research and farmer experience that showed that the risk from not overfertilizing was minimal; and recognition that excess N fertilization might be contributing to environmental contamination.

Legumes, through the symbiotic relationship with *Rhizobium* bacteria have the ability to convert atmospheric N (N_2) into plant available N. Over the last quarter century, annual legume N contributions have increased from just under 0.03 million ton to 0.5 million ton (Figure 3). This large increase was due solely to an increase in soybean acreage and yield. It was assumed that soybeans fixed 2 lb of N per bushel of beans, alfalfa fixed 200 lb of N per acre, and other legume hays produced 90 lb of N per acre.

What goes up, must come down—such is the case with N compounds. Nitrogen compounds are lost to the atmosphere through volatilization from manure or urea, and through combustion of fossil fuels, including

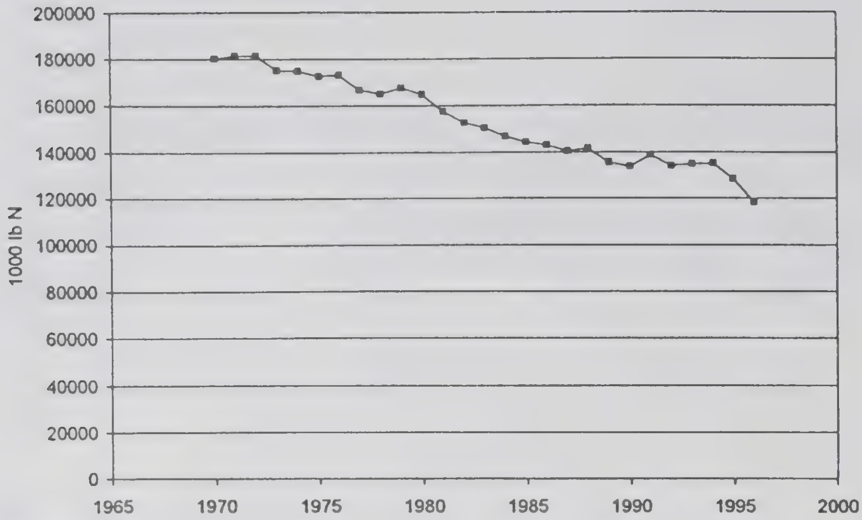

Figure 4 • Net N contribution from manure production in Illinois

internal combustion engines. Compounds resulting from these reactions recycle in precipitation but also to a lesser extent in dry deposition onto the landscape. This process, referred to as atmospheric deposition, is a significant source of N for the balance. These values were derived from data collected through the National Acid Deposition Program and National Trends Network. This collection system did not begin until 1984; thus, the prior years were estimated using the average values from 1984 to 1996.

Contrary to the impression that one might get from reading the popular press about megalivestock farms, Illinois has shown a decrease in manure N production of nearly 50% in the last quarter century (Figure 4). Manure N production numbers were determined by multiplying the coefficients for manure N produced per day for each animal class times the number of animals produced in Illinois. The coefficients for manure N production and for storage and application loss were obtained from Midwest Plan Service Publication No. 18 and animal numbers were obtained from the Illinois Crop Reporting Service. The values reported in Figure 4 are net manure-N, taking into account the volatilization losses that occur during storage and application.

Nitrogen production from human waste has remained relatively constant over the time period evaluated because the population in Illinois has remained relatively constant, ranging from a low of 11.1 million in 1970 to a high of 11.8 million in 1996. Human N input was calculated by multiplying total population times 9.69 lb of N per person per year.

Nitrogen Output

Either through direct removal in the grain or canopy volatilization, crops account for the majority of N removal in Illinois (Figure 5). The amount of N removed in animal products is small in comparison to crops, but N loss through denitrification, immobilization, and volatilization of fertilizer materials is substantial.

Nitrogen removal in harvested crops increased from just over 0.75 million ton in 1970 to nearly 1.75 million tons in 1994 (Figure 6). Improved varieties, better cultural practices, and increased N fertilizer use account for the increase in grain production and thus increased removal of N. Even though fertilizer use leveled off in the late 1980s, crop yields continued to climb, indicating that more N was being applied than needed for optimum crop production during the 1980s.

Volatilization of N compounds from plant leaves is a relatively new concept. Researchers in Nebraska and at other locations have demonstrated that significant amounts of N are lost to the atmosphere through plant leaves. The values that were used for this paper were 35,

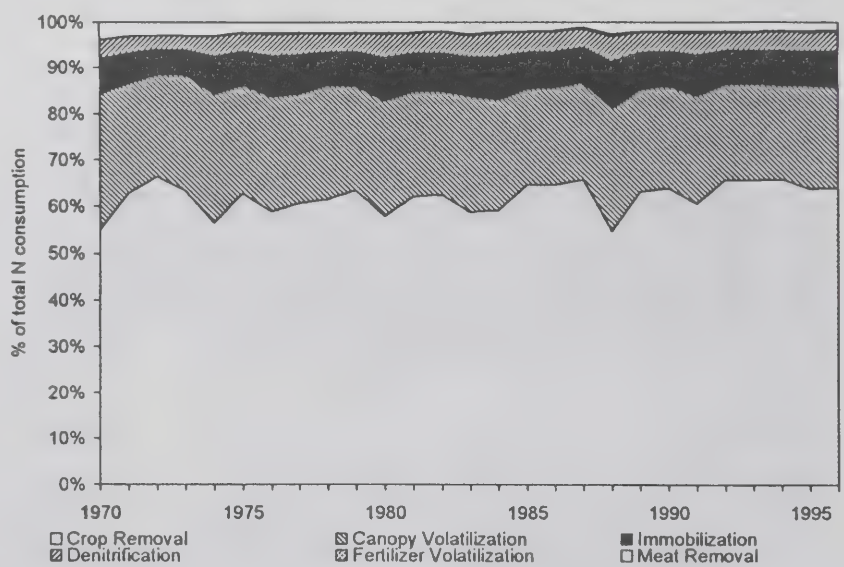

Figure 5 • Relative N consumption of loss from various sources in Illinois

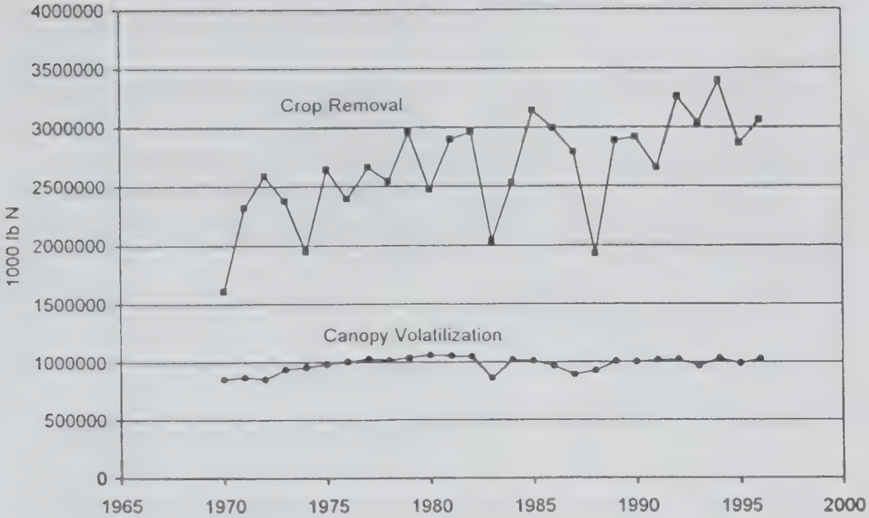

Figure 6 • N removed by harvested crops in Illinois

45, and 50 lb of N/acre for wheat, soybeans, and corn, respectively. Because this concept is in its infancy, there is not an adequate database to alter these values based on environment or productivity, or to determine if losses from one plant are absorbed by another.

Immobilization is the process whereby microorganisms convert inorganic N into an organic form. Similar to mineralization, this process is temperature and moisture dependent; however, there is not an adequate model available to predict year-to-year variation. As a result, 40% of a fertilizer application was assumed to be immobilized.

Denitrification is the process whereby microorganisms reduce nitrate (NO_3) to volatile N compounds. This process occurs when soils are excessively wet during warm periods. For purposes of this balance, 10% of the fertilizer was assumed to be denitrified.

In the early part of the 1970s, N removal by animal products was nearly as large as denitrification, but in the 1980s and thereafter, animal production decreased and fertilizer consumption and consequently denitrification increased to the point where denitrification is nearly double animal product removal of N. Volatilization of N from surface applications of urea-containing materials was estimated to be 5% of the total urea N.

Nitrogen Balance

From 1970 to 1996 Illinois was net positive in N (Figure 7). Excesses of 0.2 to 0.4 million ton of N were characteristic of the 1970s and early part of the 1980s. Although this number is large, when allocated over the >20 million crop acres, it amounts to from 20 to 40 lb per acre. The huge excess in 1988 could be attributed to the low yields resulting from the severe drought. The steady decrease in the excess contribution that has occurred from the mid-1980s to present can be attributed to high crop yields and lower fertilizer sales. Another way to look at the balance is excess as a percentage of the total N input (Figure 8). When averaged across all years, the average excess has been 8.9% of the total input. This value has dropped to <5% for most of the 1990s.

Phosphorus Input

Fertilizer sales are the predominant P input into Illinois (Figure 9), accounting for 75 to 80% of the total input. Unlike for N, we did not include an estimate of the amount coming from soils as there is no good model available to predict that quantity on a state-wide basis. Fertilizer sales reached a peak in the mid-1970s and have since been on a steady decline (Figure 10). Simi-

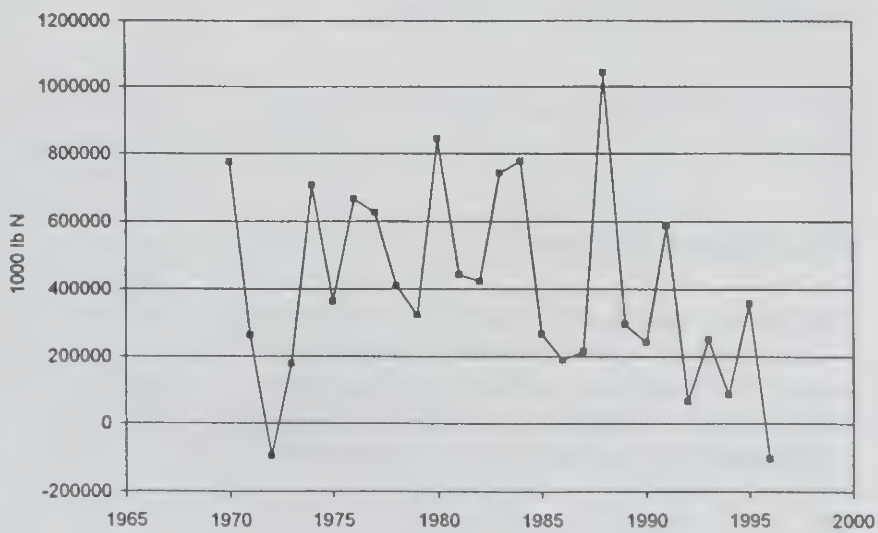

Figure 7 • Net N in Illinois (input minus output)

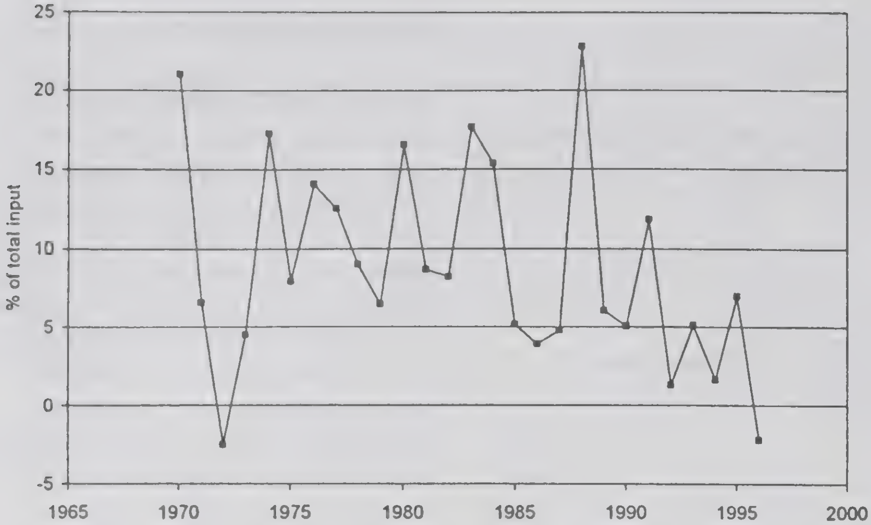

Figure 8 • Net N in Illinois as a percent of total nitrogen input

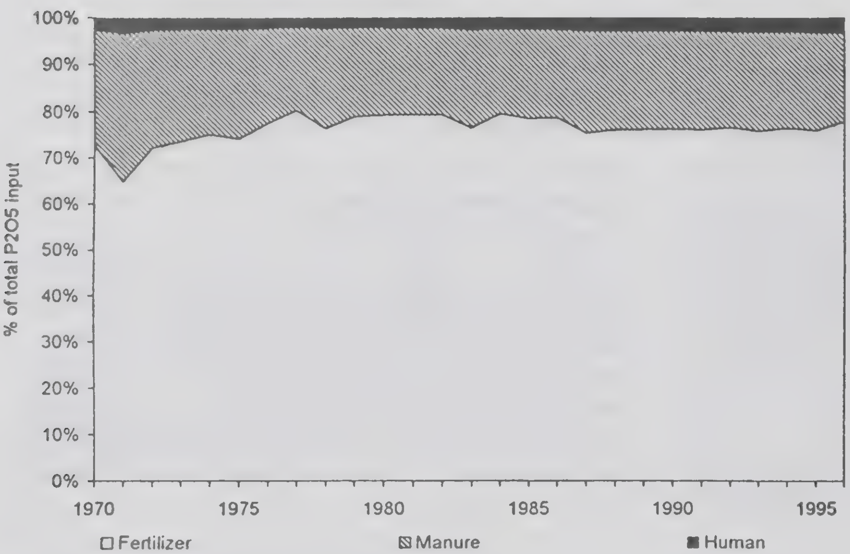

Figure 9 • Relative contribution of P input sources

larly, manure P has decreased 50% since its peak in 1970.

Phosphorus Output

Phosphorus removed in harvested crops dominates the P output budget (Figure 11). Over the last quarter century, P removal by crops has more than doubled, going from <0.3 million ton in 1970 to >0.6 million ton of phosphate in 1994. Animal products account for <5% of the total P removed in the state.

Phosphorus Balance

Throughout the 1970s and early part of the 1980s, Illinois used from 0.2 to 0.4 million ton more P than was consumed (Figure 12). Since 1985, P input has been less than output in all but 2 yr.

Summary

Illinois has a track record of significantly more N and P input than output through the 1970s and early part of the 1980s. From the late 1980s into the 1990s, input has more closely mirrored output, and for P, input has fallen short of output. Nitrogen overapplication probably resulted in a loading of the soil system with N to the point that leakage was increased above background levels; as a result, some water systems were contaminated with nitrates. The near balance of N input to output that has been occurring for the last 8 to 10 yr suggests that leakage of nitrate in excess of background levels into water supplies should start to lessen. It will take some time at current input-to-output ratios, however, for this excess to be consumed and leakage to return to near-background levels.

Excess P used during the 1970s should not be looked upon as bad management, because many soils needed this excess to bring soil test levels to the point that would optimize yield. There is still a small percentage of Illinois soils that need this build-up of P. There is no reason to suspect that the negative input P levels observed in the 1990s will result in severe yield reductions in the near future bacause many producers have been using the reserves that they had built in previous years. The primary concern will be if producers under apply for long periods of time on soils that initially have a marginal soil test level because yields will be adversely affected.

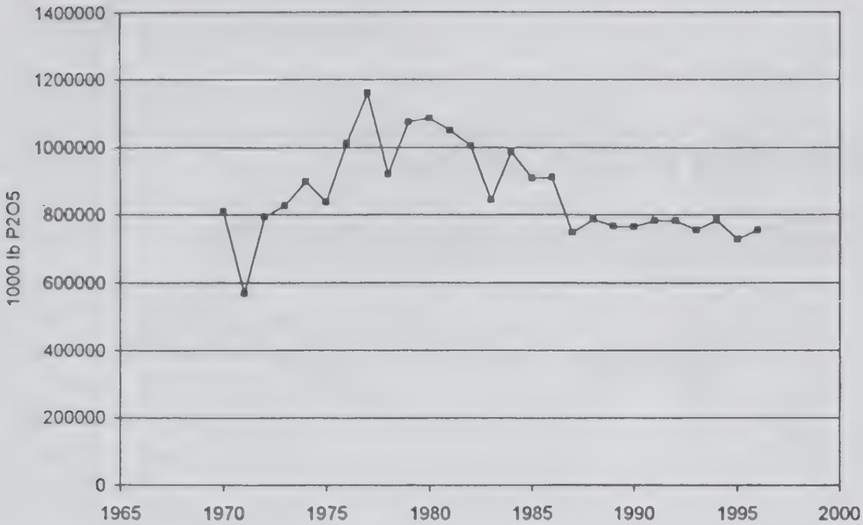

Figure 10 • Illinois P fertilizer sales

Figure 11 • Relative removal of P from Illinois

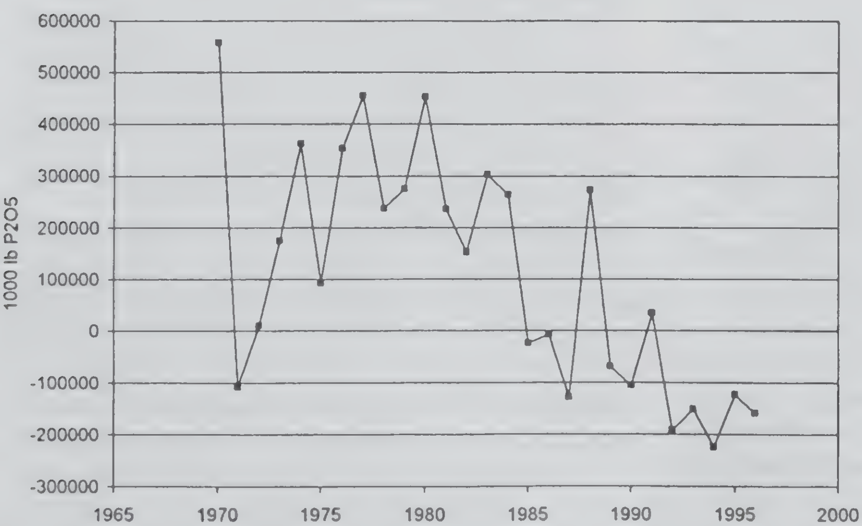

Figure 12 • Net P in Illinois (input minus output)

MANAGING PHOSPHORUS: AGRONOMIC AND ENVIRONMENTAL CONCERNS

Regis Voss

Phosphorus (P) is an essential nutrient for terrestrial and aquatic plants. The beneficial effects of P on the growth and yield of crops has been recognized. There is increasing concern and attention being given to P losses from agricultural soils. Substantial amounts of P entering surface waters (lakes, other surface impoundments, and streams) contribute to accelerated eutrophication of lakes and reservoirs. Eutrophication is a process by which a water body becomes rich in dissolved nutrients and, often, seasonably deficient in oxygen. Eutrophication due to excessive algal and other plant growth and their ultimate decomposition, which consumes oxygen, limits the use of surface waters for aesthetics, fisheries, recreation, industry, and drinking.

In recent years there has been a change to more intensive agricultural production systems, especially the localization and intensification of animal production systems. With this intensification has come a buildup of soil P levels in site-specific areas to levels rarely encountered in past decades. As a result, there is increased potential for P losses from these site-specific areas and environmental risk to affected surface waters. Many of these high-P soil-test areas are located near sensitive water bodies. When adsorption sites for P in the soil become saturated, P is potentially more available for runoff and leaching losses. Traditional soil test extractants for P were developed by research to provide indexes of P availability to plants. There currently is no standardized P testing procedure to identify critical soil P levels associated with environmental risks. There is a need to develop field and soil measurements to help identify P problem areas and to target these areas with acceptable management practices to achieve satisfactory economic and environmental solutions.

The Problem

There is a general conclusion that aquatic growth in inland surface waters is P limited (i.e., as P concentration in surface water increases, aquatic growth increases). According to the NCR (1993), overall trends indicate about equal numbers of U.S. rivers with increasing and decreasing P loads. In general, decreases are linked to point-source reductions and increases are linked to nonpoint-source increases that are associated with increased sediment loads and agricultural land use.

The critical concentration of P associated with accelerated aquatic growth is very low, 0.01 parts per million (ppm), but a range from 0.01 to 0.03 ppm seems to be accepted (NCR 1993). These values are roughly one-tenth of the soil solution concentration critical for plant growth. The U.S. Environmental Protection Agency (US EPA) has not yet developed P water-quality criteria for freshwater bodies but has established 0.001 ppm elemental P as a criterion for marine and estuarine water (Parry 1998). Daniel et al. (1998) stated, however, that water quality criteria have been established to control eutrophication (US EPA 1986). For example, total P should not exceed 0.05 ppm in streams entering lakes or reservoirs or exceed 0.025 ppm within lakes or reservoirs. For the prevention of plant nuisances in streams or other flowing waters not discharging to lakes or impoundments, the concentration of total P should not exceed 0.10 ppm. A dissolved P concentration of 1 ppm is the limit required of sewage-treatment output and one advocated by some as a critical flow-weighted-mean-annual concentration for agricultural runoff.

Transport of Phosphorus

Phosphorus can reach surface waters as P dissolved in runoff water, P attached to soil particles contained in soil erosion, and P contained in tile effluent. Not all agricultural land, nor all that contained in a watershed, contributes to any or all of these processes.

Phosphorus potentially available to algal uptake is termed bioavailable phosphorus (BAP), which is comprised of dissolved phosphorus (DP) and particulate forms of phosphorus (PP). Dissolved P is mostly available for algal uptake, but PP, associated with eroded sediment and organic matter, contributes a variable but long-term source of BAP (Sonzogni 1982, Sharpley and Smith 1991).

If runoff containing DP and PP from agricultural fields enters a surface stream, the DP may be adsorbed (concentration decreases) by stream sediments or PP may be desorbed (DP concentration increases), depending on the P sorption saturation of the stream sediments. Thus, the concentration and amount of BAP entering a lake or reservoir may be different from that leaving an agricultural field. Sediments with high P concentrations entering a lake or reservoir can contribute BAP by desorption for a prolonged period of time.

The effect of BAP entering lakes or surface impoundments on eutrophic growth depends greatly on their characteristics. Turbidity, depth of water, flushing rate, stratification, and background P level of lakes or reservoirs affect growth of algae and other aquatic vegetation. In general, P control strategies have greatest benefit on deeper, stratified lakes with a low flushing rate (<6 times per year) and low background levels of P.

Phosphorus Loss from Agricultural Fields

Studies have found higher concentrations of DP in surface water runoff from no-till fields with surface crop residue than in runoff from conventional-till fields (Romkens et al. 1973). Also, studies have identified higher runoff concentrations from fields covered with frozen crop residue, such as alfalfa, than from tilled fields (Wendt and Corey 1980), and from fields with surface-applied, non-incorporated fertilizer, manure, or both than from fields with incorporated fertilizer (Truman et al. 1993).

Rainfall interacts primarily with the 0- to 2-in. layer of surface soil (Oloya and Logan 1980, Sharpley and Smith 1989). As a consequence, there is a very good positive relationship between soil test P levels and concentrations of DP in runoff (Pote et al. 1996), as shown in Figure 1. Losses are exacerbated by stratification of surface applied P in no-till and conservational till systems, where soil test P levels are greatest in the 0- to 2-in. layer (Triplett and Van Doren 1969, Robbins and Voss 1991).

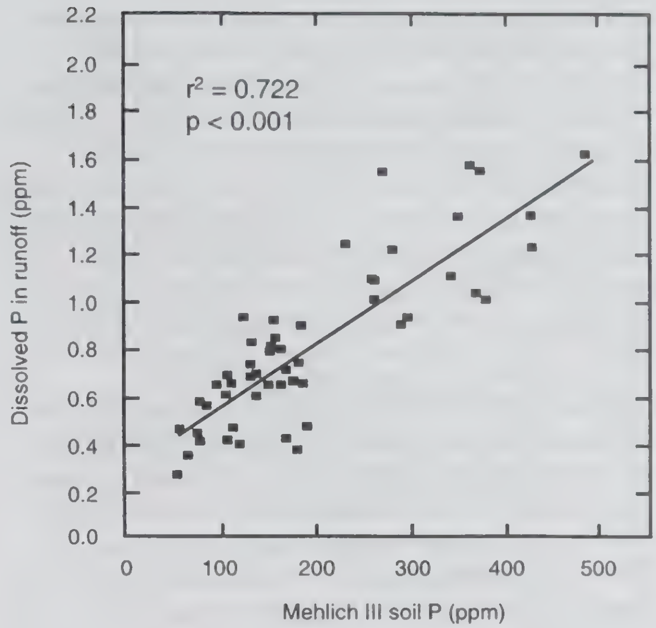

Figure 1 • Relationship between Mehlich III extractable P in Captina surface soil and dissolved P in runoff (adapted from Pole et al. [1996]).

There has been a general increase in soil test P levels in the U.S. since World War II because of P applications. A 1989 summary of soil test values showed that in several states >50%, and in some states 75%, of soil test P samples tested high (PPI 1994). A recent soil test summary from 1997 (PPI/PPIC/FAR 1998) indicates that many agricultural soils remain in the high and very high categories. For many states, percentages of tests with high P levels are similar to 1989 percentages, but trends show decreasing numbers of tests with high P levels in some important agriculture states in the Midwest, such as Indiana, Illinois, Iowa, Minnesota, and Ohio. In other states, such as Arkansas, Wisconsin, North Carolina, and Delaware, soil test P levels continue to increase.

A nutrient budget analysis for Iowa and Wisconsin indicates that these up or down trends might be explained based on P use and removal. Assuming that all collectable manure in Iowa was applied to cropland, P removal by crops exceeded the inputs in 1996 by 10%. In Wisconsin P crop removal is only 84% of P inputs (Bundy 1998). In many cases the problem of elevated

soil test P levels is associated with regions where intensive animal production facilities exist and animal manure supplies exceed crop needs on available agricultural land. County-based estimates of the potential for P available in animal manure to meet or exceed crop removal are available to identify local soil test P problem areas (Lander et al. 1998). The potential for P loss from surface runoff and, in some situations, subsurface leaching, increases as soil test levels exceed critical soil test values established for crop needs (Sharpley et al. 1996).

Because commonly used soil test procedures (e.g., the Bray and Kurtz P-1, Mehlich III, and Olsen tests) were developed to provide indexes of P availability to plants, a more rigorous test is desirable to indicate the loss of DP for environmental interpretation. Soils adsorb or desorb P depending upon the P sorption saturation of the soil, which is defined by the following equation:

$$\text{P sorption saturation} = \frac{\text{Extractable soil P}}{\text{P sorption capacity}} \times 100.$$

More P is desorbed (or released) from soil and lost through runoff or leaching as P sorption saturation increases (Figure 2). A better relationship was found for DP concentration and P saturation than for DP concentration and soil test P indexes (Sharpley 1995). The P sorption saturation test provides an integration of soil characteristics, but it is time-consuming and costly. This method, like routine soil tests, does not predict total loss of DP, which depends on runoff volume. The P sorption saturation approach does indicate potential for loss of DP. The Dutch have designated a critical P saturation value of 25% (Van der Molen et al. 1998).

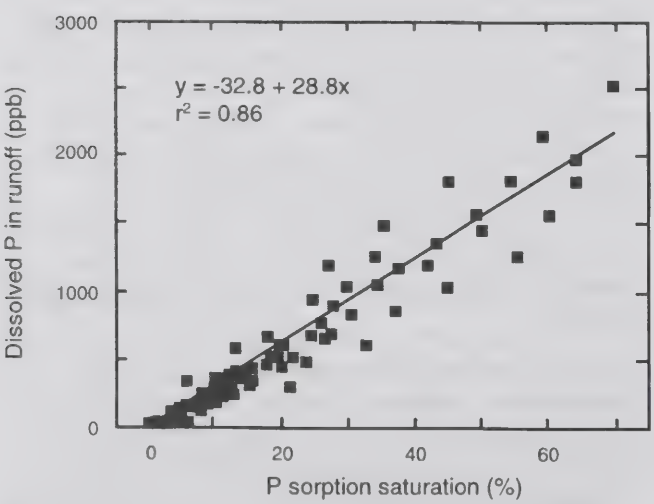

Figure 2 • Relationship between the dissolved P concentration of runoff and soil P sorption saturation of surface soil (0–0.4 in.), 7 d after poultry litter application (adapted from Sharpley [1995]).

Phosphorus in Eroded Soil Sediment

Phosphorus associated with eroded soil sediment is termed particulate phosphorus (PP). Eroded sediment tends to have a higher P concentration than its original source, but excessive soil erosion may dilute the concentration in the total eroded sediment. Particulate P can be 75 to 90% of the P transported in runoff (Schuman et al. 1973).

Although PP loss may be greater than DP loss, only a portion of PP is bioavailable phosphorus (BAP) because some of the adsorbed P will not desorb and is not available to plants. Phosphorus extracted by a NaOH solution is more closely associated with BAP concentration and availability to algae than is soil test P (Wolf et al. 1985). A simpler procedure using iron oxide-impregnated paper strips to determine the BAP directly related to algae growth was adapted by Sharpley (1993a, b) (Figure 3). The iron-oxide strips function as a P-sink, adsorbing P released from soil sediment and simulating P removal by algae.

Although specific analytical procedures provide indexes of P that are related to concentrations of DP, PP, and BAP loss in runoff water and eroded sediment, test results are not reliable indicators of P amounts lost from fields or arriving to surface waters. Test results do indicate a potential for loss, if combined with estimates of runoff or erosion potential.

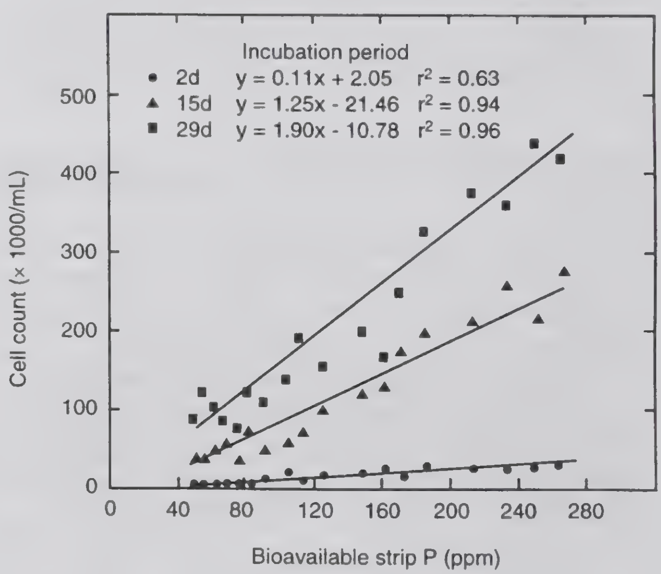

Figure 3 • Relationship between the bioavailable strip P content of runoff sediment and P-starved *S. capricornutum* (algae) growth during 2-, 15-, and 29-d incubations (adapted from Sharpley [1993]).

Phosphorus in Tile Effluent

Because P is considered to be immobile in the soil, there is generally little concern that it will be lost in tile drainage. There are, however, locations with sandy or organic soils where tile effluent has high concentrations of P (Duxbury and Peverly 1978). In the Netherlands, where sandy and organic soils with high water tables are prevalent, restrictions on P use are imposed. Studies in the United States have in general found very low concentrations of DP in tile drainage, but concentrations frequently exceed the projected critical value of 0.01 ppm of P for algae growth (Baker et al. 1975). In one study, P concentrations in tile effluent increased as rates of manure increased, indicating that excessive manure loading can contribute to DP loss even though economic loss is negligible (Hergert et al. 1981).

Immediate concerns are to manage and monitor P concentrations in tile drainage from areas where soil P concentrations are already very high, soil P sorption capacities are low, and subsurface transport is enhanced by tiles and surface ditches. Phosphorus-saturated soils could lead to prolonged loss of DP in tile effluents. In many situations, loss of P in tile effluent will be of little consequence relative to surface runoff and erosion (e.g., in fine-textured soils that are judiciously fertilized in accordance with soil testing recommendations and that have low degrees of P saturation).

Problem Assessment

Because of the diversity in the agricultural landscape, there is a wide range in the potential loss of P from fields within the landscape. Contributing to the diversity are physical and chemical characteristics of the soils, landscape form, crop and plant vegetation, crop production cultural practices, P level of the soils, and method of P application. Most watersheds contain field sites that are different in one or more characteristics. To assess the potential risk of P movement to surface waters from various landforms subjected to different management practices, a Phosphorus Index was proposed by Lemunyon and Gilbert (1993). This index considered 8 weighted factors: soil erosion weighted × 1.5; irrigation erosion × 1.5; runoff loss × 0.5; soil P test × 1.0; P fertilizer application rate × 0.75; P fertilizer application method × 0.5; organic P source application rate × 1.0; and organic P source application method × 1.0. Rating values for each level of these site characteristics were assigned (low = 1, medium = 2, high = 4, very high = 8), multiplied by their respective weighting values, and

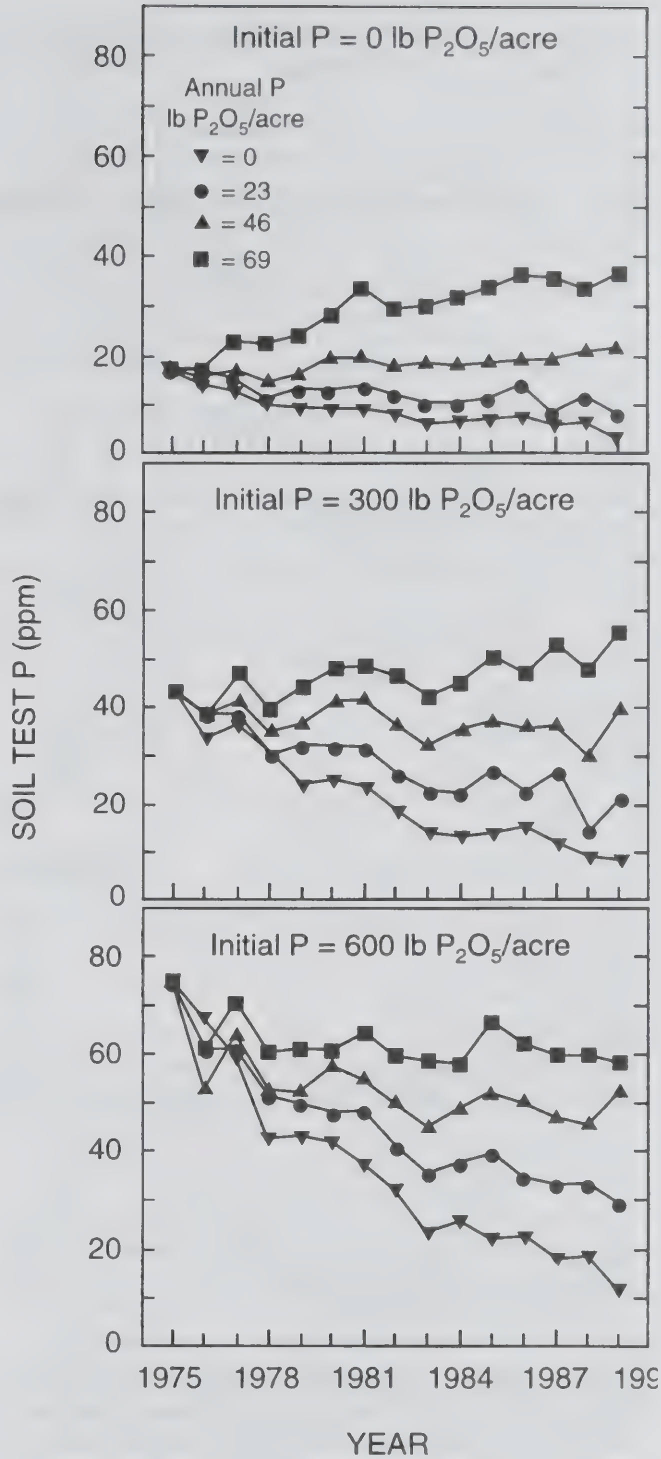

Figure 4 • Soil test P values (Bray-P_1) as affected by initial and annual applications of P fertilizer (adapted from Webb et al. [1992]).

summed over the 8 items. The resulting value provides the relative vulnerability of a site for P loss. This index has been applied in evaluating watersheds and although it may need refinement, it has been satisfactory in

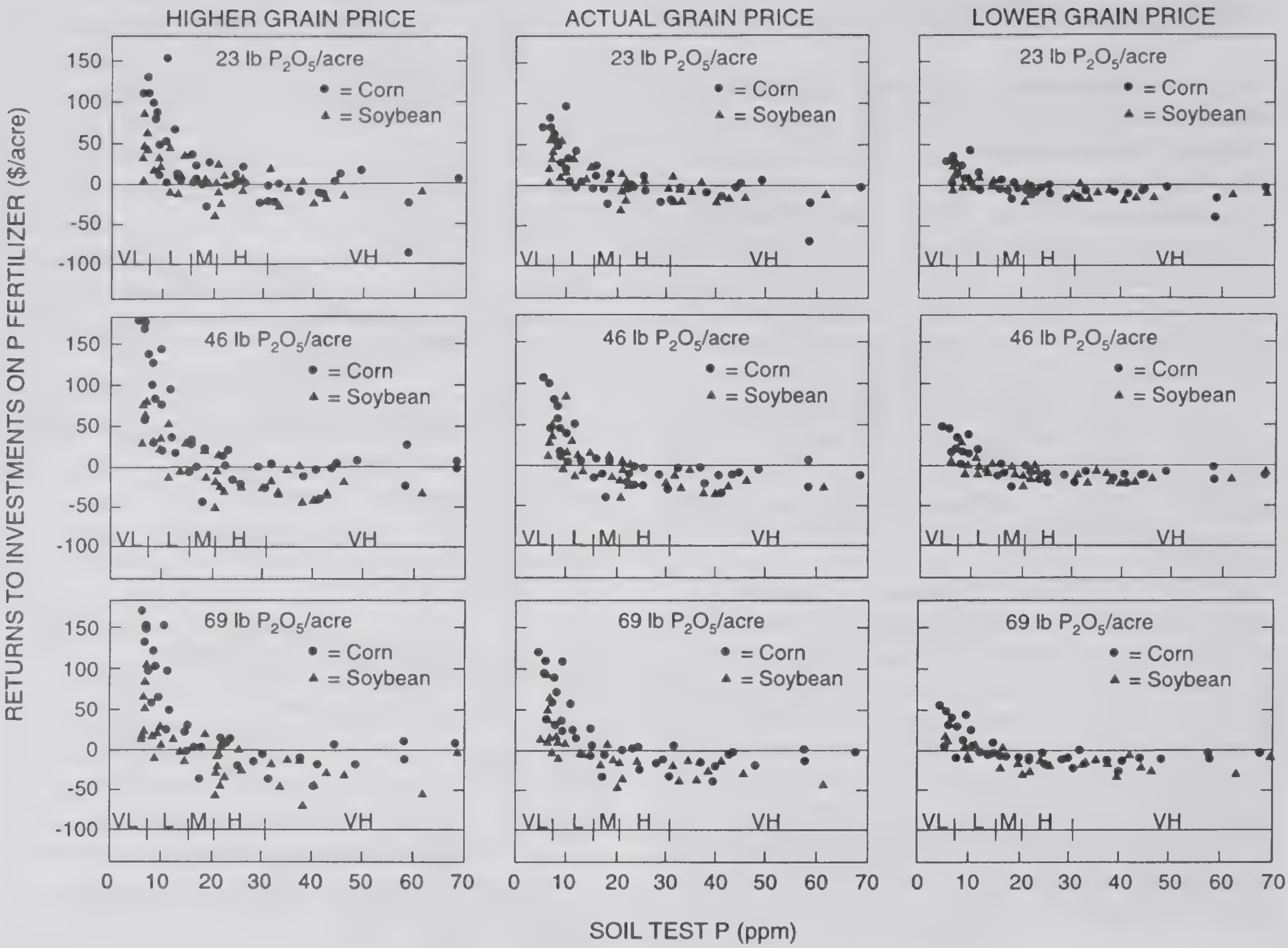

Figure 5 • Relationships between soil-test P values (Bray-P_1) and annual net returns to investment on 3 annual P rates at various grain prices. The actual prices were annual averages for the United States from 1976 to 1989. Higher prices were the prices for each year increased by 50%, and lower prices were the prices for each year reduced by 50% (adapted from Webb et al. [1992]).

identifying P sources within a watershed that will require more management to minimize P loss in runoff and maintain crop productivity.

A more recent approach is simulation modeling through computer programs. This approach permits evaluation on a watershed basis and predicts the effect of various P management and cultural practices on potential P losses. This approach will probably require more input than the Phosphorus Index, which can be assessed with locally available information.

Management Practices Affecting Phosphorus Loss

Several management practices can affect P loss from agricultural fields. These practices include soil test P level maintained; time, rates and method of P application; tillage that affects erosion and amount of crop residue on the soil surface; amendments to manure and soil to reduce P availability; and vegetative filter strips adjacent to surface water. Feed and feed additives can reduce the amount of P in animal manure.

Applying manure or fertilizer P to frozen or snow-covered ground results in more P loss in runoff than when nutrients are applied to bare unfrozen ground. The P concentrations in runoff from the first rain after a surface-manure application are greater than that in runoff from subsequent rains. As time between manure application and rain increases, P concentrations in runoff decrease. Timing of manure and fertilizer applications are important if these materials are surface applied. Injecting manure and banding fertilizer P into the soil eliminates most of the potential for runoff P.

Because of the relationship between surface soil test P values and loss of P in runoff and erosion, building and maintaining very high soil test P values becomes an environmental concern. Data from Iowa, obtained from a corn (*Zea mays* L.)–[*Glycine max* (L.) Merrill] soybean sequence grown on a soil with a very low subsoil level of P, show it may take a decade or more to reduce a very high soil test P to a responsive range (Figure 4). Also, economic returns are negative for maintaining very high soil test values (Figure 5) (Webb et al. 1992).

Tillage on soils where runoff and erosion may occur increases total P loss with variable BAP concentrations and amounts as previously cited. No-tillage or very reduced tillage that leaves crop residue on the surface of similar soils reduces total P and BAP loss but may increase DP in runoff water. Periodic inversion of P-stratified surface soils may be advantageous to reduce concentrations of P at the soil surface and potential for P loss.

Amendments such as aluminum sulfate, ferrous sulfate, or coal combustion products can be added to manure or soil to reduce soluble P. These amendments can affect other soil properties and should be investigated before applications of such amendments are recommended practice. An organic compound, polyacrylamide, has been used on western irrigated fields and has been shown to reduce loss of P and sediment from these fields.

Much of the P in corn grain is in the form of phytic acid, which is unavailable to monogastric animals (e.g., swine and chickens). Most grain P is excreted in manure. Phytase enzymes, added to feed rations, increase the availability of P in corn grain and reduce the amount of P excreted. Corn genetic material with a low phytic acid P content has been identified. Feeding trials using this corn grain have shown increased P availability to animals and reduced P content in manure (Ertl et al. 1998). Reduction of P concentrations in manure could reduce P loadings of fields where manure application is based on the nitrogen requirement of the crop to be grown.

Vegetative filter strips between agricultural lands and surface waters can be effective in reducing the amount of sediment and PP entering surface waters but may increase the amount of DP in runoff waters.

Crop and Soil Management Options

Crop and soil management options exist to minimize potential P losses into surface waters.

1. Identify fields that have the greatest potential for P loss.
2. Apply fertilizer P or manure P according to soil test values for the crop to be grown.
3. Do not build and maintain excessively high soil test P levels.
4. Minimize soil erosion with appropriate cultural practices.
5. Where possible, incorporate or knife in fertilizer or manure without destroying crop residue required for soil conservation purposes.
6. Establish and maintain vegetative filter strips where runoff leaves a field and along streams and drainage ditches where agricultural runoff water enters these surface waters.
7. Grow high-P-removing crops that provide an economic return to the producer.
8. Periodically invert P-stratified surface soils by primary tillage.

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VALUE OF BUFFER STRIPS FOR WILDLIFE

Richard E. Warner, Larry M. David, and Phil C. Mankin

A filter strip is a band of dense herbaceous vegetation between an agricultural field and a body of water, such as a stream, river, pond, or lake. The use of filter strips is widely promoted by natural resource agencies in Illinois to buffer some of the deleterious effects of intensive cropping on aquatic resources. Sediments, nutrients, and pesticides are the primary contaminants of rivers and streams in the state. Sedimentation dramatically alters the living conditions for aquatic organisms, reducing light penetration, affecting water chemistry, and altering bottom substrates that support aquatic life. Crop nutrients reduce the oxygen available in aquatic systems and also affect water chemistry in other ways. Moreover, agricultural pesticides can be highly toxic to aquatic organisms.

Filter strips do more than just remove sediments from runoff. They can improve water quality by filtering, absorbing, trapping, and decomposing sediments, nutrients, and pesticides passing through the vegetation from nearby agricultural fields. Filter strips reduce herbicide runoff by an average of 48%, with the efficiency of herbicide varying relative to such factors as soil type, soil water content, runoff volume, buffer width, and vegetation.

Filter strips also can benefit wildlife. The grassy and other herbaceous vegetation at the land–water interface provides cover needed by wildlife in the intensively farmed landscapes of Illinois. Many of the birds in Illinois, for example, were adapted to the prairie and have declined precipitously in recent decades in row crop environments. Benefits to wildlife by filter strips, however, should not be assumed. These strips of vegetation must be carefully managed to optimize their value as habitat. We illustrate some of the considerations for grassed filter strips for use by wildlife.

Diversity of Species and Uses

There are several management practices that encourage a diversity of wildlife species to use filter strips. These practices include the following:

Landscape elements. Many species of wild vertebrates benefit from having a variety of landscape elements in close proximity. Thus, filter strips close to other permanent cover such as woods, pasture, farmsteads, and pasture are especially attractive to wildlife. Wildlife also benefit from nearby crop fields where conservation tillage is applied.

Heterogeneity of vegetation. A tract with a variety of plant species is more likely to provide critical resources for wildlife, and the uneven profile of such vegetation attracts more species of nesting birds. Some birds need tall grass cover (dickcissel, common yellowthroat, song sparrow), whereas others prefer shorter grasses (vesper sparrow, grasshopper sparrow, eastern meadowlark). A variety of plants host more beneficial invertebrates as well. Adding shrubby vegetation along filter strips also will enhance animal diversity.

Tract width. The number of species attracted to grassy strips increases with width. Wider tracts not only attract more species but also are more likely to afford them safe cover. Wider strips provide nest cover for many ground-nesting species such as ring-necked pheasants, northern bobwhites (quail), gray partridge, rabbits, meadowlarks, dickcissels, redwings, mallards, ground nesting sparrows, brown thrashers, and sedge wrens.

Mechanical disturbances. Most wildlife species are sensitive to farm disturbances, especially during reproduction in spring and summer. Nesting wildlife are prone to destruction by mowing and field implements

passing through the vegetation. Mowing during the reproductive season is the single most important problem facing grassland-nesting birds and other wildlife. Information on the fates of pheasant nests in mowed hayfields in Illinois illustrates the devastation caused by mowing during late incubation. In hay mowed the week of 11–17 June, 37% of nests was destroyed by mowing and incubating hens were struck and killed or badly injured at 73% of destroyed nests. In the following 2 wk, 23% of nests was destroyed by mowing and hens were hit at 67% of destroyed nests. Similar losses can be expected for quail, meadowlarks, and other ground-nesting birds. Although some songbirds nest off the ground in taller vegetation and may not suffer loss of incubating females, they suffer similar nest losses. Nursing female cottontails and their nests also are destroyed by mowing, and fawns are frequently injured as well. After filter strip vegetation becomes well established, it should remain unmowed until at least 1 August to avoid such destruction of wildlife.

Chemical disturbances. Pesticides can be a direct or indirect detriment to wildlife. For example, insecticides are extremely toxic to most wild vertebrates at the time of application. Moreover, herbicides reduce plant variety and are also toxic to eggs and young wildlife.

Upland Game

Filter strips also can serve as brooding and nesting cover for pheasants and quail. They can provide roosting areas for the game birds all year. Wider filter strips with dense tall prairie grasses, such as switchgrass, provide protection from the winter weather and concealment from predators.

There are distinct differences in grassy cover attractive to quail and pheasants. Pheasants nest and roost in dense grass or legume cover of intermediate height. Quail nest in dense clumps of fine-stemmed grasses. Although the vegetation at the immediate quail nest site is usually dense, the general habitat type is clumpy with some bare ground interspersed. Quail seldom nest in dense stands of legumes or grasses such as hayfields, which would provide preferred pheasant nest cover. Thus, the best quail nest cover is attained through management of plant succession rather than by planting grasses.

Both quail and pheasant chicks need to forage on insects during the early weeks of life. Good brood cover provides overhead canopy but is open at the ground level. Most young birds cannot penetrate thick, sod-forming grasses. Brood cover must have a diversity of plants and support large numbers of insects. Tall native grasses, such as switchgrass, big bluestem, and Indiangrass can provide winter cover for either quail or pheasants. Brood cover or winter cover plantings, as well as nest cover, could be included on filter strips. Plantings in the quail range should be thinner and managed to keep a clumpy character with more bare ground compared with plantings in the pheasant range.

Good pheasant habitat consists of fields, patches, or strips of dense grass or legume cover interspersed in cropland. Good quail habitat has ample, well-distributed food sources in an area of cropland, woodland, grassland, and brush. A diversity of cover types usually provides the "edge" needed by quail. The greater the interspersion of cover types, the greater the amount of "edge" and quail numbers.

Other Management Considerations

Landowners who intend to try to plan for wildlife filter strips should be aware that plantings of tall fescue have a negative impact on almost all wildlife species. Tall fescue tends to dominate all other vegetation, has a matlike structure that is impenetrable to small birds, and contains a fungus that is toxic to rabbits, livestock, and other animals. Fescue should always be avoided. In many cases, reed canary grass has aggressive characteristics similar to fescue.

Grass Species for Filter Strips. Grasses are broadly classified into 2 groups—warm and cool season—based upon the seasons of the year they are most actively growing. Warm-season plants can be especially good for wildlife filter strips. Their tall (2–8 ft), upright growth form provides good winter protection for wildlife. Because they usually do not form a thick sod, they provide more openness at ground level for brood cover. Suitable native warm-season grasses for filter strips include Indian grass, big bluestem, little bluestem, sideoats grama, eastern gamagrass, and switchgrass.

Seedings with Legumes. The inclusion of legumes is important in providing nitrogen for healthy and vigorous grass stands and to provide diverse vegetation for producing the various insects important as food for gamebird chicks. Legumes compatible with warm-season grasses are alfalfa, lespedeza, birdsfoot trefoil, and especially the native legumes, such as Illinois bundleflower, leadplant, purple prairie clover, prairie acacia, and round-headed lespedeza. The most desirable cool-season grass and legume mixtures differ from the pheasant range to the quail range. Bromegrass and

alfalfa are the most favorable for pheasant nesting cover. Finer stemmed grasses such as redtop, timothy, and bluegrass are preferred by bobwhites. Korean lespedeza, an excellent quail food, is the best legume for southern Illinois (roughly south of I-70). In the western Illinois bobwhite range, red clover or yellow sweet clover are suitable legumes. The inclusion of legumes is important in providing nitrogen for healthy and vigorous grass stands and to provide diverse vegetation for producing the various insects important as food for gamebird chicks. In addition to legumes, forbs are also a desirable addition. Examples of desirable forbs include wild flowers such as gayfeather, compassplant, coneflower, and Maximilian sunflower.

Long-Term Management. Management is required to maintain cool season mixtures in both pheasant and quail ranges. Brome grass–alfalfa stands require frequent August mowing to retain the alfalfa in the mixture. Grasses in the quail range require periodic disturbance by burning or strip disking to reduce litter, provide bare ground, and encourage growth of a diversity of native food plants.

Herbicides. Herbicide tolerance is important in filter strips because runoff from adjacent crop fields often carries chemicals to kill grasses. These chemicals generally affect cool-season grasses more than warm-season grasses. Although warm-season grasses are not tolerant to all grass-killing chemicals, they are resistant to several used on corn and milo.

Filter Strips and Farm Programs

There are several programs and agencies that support the establishment of filter strips in Illinois. Three are listed herein.

Conservation Reserve Program (CRP). Some filter strips may qualify for CRP whereby private landowners can participate by enrolling land in a 10 or 15 yr contract with the United States Department of Agriculture. The landowner is paid an agreed-upon per-acre rate for land that the CRP sets aside to protect from soil erosion and to filter pollution from water bodies and public well heads. Filter strips cannot be separated from the water body by trees. There is a continuous enrollment for land qualifying for filter strips in CRP. Moreover, there are other continuous sign-up practices that are relevant, such as shallow-water areas for wildlife, shelterbelts, grassed waterways, riparian buffer strips, living snow fences, and areas affected by salt damage. These practices qualify for an additional 20% incentive payment. Filter strip widths on CRP may vary according to the slope of the land. An Natural Resources Conservation Service (NRCS) technician will design the width based on required minimums and maximums, along with the landowner's desires.

Conservation 2000—Conservation Practices Program. Conservation 2000 is a program administered by the Illinois Department of Agriculture and county soil and water conservation districts (SWCD) that provides up to 60% cost-share to landowners with highly erodible land, for constructing eligible practices for conserving soil and protecting water.

Vegetative Filter Strip Assessment Law. As an incentive for installing protective vegetative filter strips on land adjacent to surface or groundwater sources, landowners may receive a reduced property tax assessment of 1/6th of its value as cropland. Vegetative filter strip design and certification assistance is available from county SWCD offices.

Consulting Agencies and Organizations

When planning for seeding mixtures for filter strips, please contact your county NRCS office or Department of Natural Resources (DNR) district office for proper seeding rates and planting dates.

Private Land Wildlife Habitat Program Department of Natural Resources. There are 35 district wildlife habitat biologists in 17 districts around the state that can provide professional advice and counsel, planting materials, and the loan of specialized habitat-planting equipment for improving habitat for wildlife. Many practices available through Acres for Wildlife can be applied to filter strip areas. Contact your DNR district office, your county SWCD office, or the Division of Wildlife Resources in Springfield [(217) 782-6384] for more information.

Pheasants Forever and Quail Unlimited. Local Pheasants Forever (PF) or Quail Unlimited (QU) chapters can assist in establishing filter strips and other habitat by supplying the landowner with most of the resources needed to complete these projects. The resources may include desired grass seed mixtures, herbicides, and in many counties specialized equipment such as native grass drills. Contact your local PF or QU chapter or county NRCS or SWCD office to see what programs and equipment are available.

SOIL HEALTH AND TILLAGE

Michelle Wander

According to the Soil Science Society of America's Ad Hoc Committee, soil quality "is the capacity of soil to function" (Karlen et al. 1997), where critical soil-property-dependent functions include soil's ability to support plant and animal growth, filter and retain matter and nutrients, and regulate water flow through the soil system (Larson and Pierce 1991, 1994). Clearly, soil quality must be maintained to meet increasing demands for food and fiber and to sustain environmental integrity. Technological change in crop management can alter the relationship between productivity and soil quality, creating a discontinuity that makes prediction of future yield trends difficult (Cassman et al. 1995). At times the very practices that boost yields also reduce soil quality (Cassman and Pingali 1995). In Illinois, where high-quality soil is taken for granted, over one hundred years of data from the Morrow Plots reveal the effects of management practices and technological innovations on corn (*Zea mays* L.) yield and soil organic matter contents (Aref and Wander 1997). Hybrids, fertilizer application, and pest control measures have increased corn yields fourfold since the trial's inception. Average corn yields since 1967 are significantly lower in the fertilized continuous corn plots than in similarly fertilized 3-yr rotation plots and increased fertilizer application rates do not significantly boost yields although that previously manured soil is presumably in better condition than never-amended soil (Table 1). These results demonstrate the cost of soil organic matter losses to yield potential but do not adequately chronicle deterioration of the soil's other soil organic matter-dependent functions or soil outputs, such as N leaching. Soil-quality assessment would help producers keep track of on- and off-site soil performance.

Table 1 • Average corn yields in the Morrow Plots since 1967 (adapted from Aref and Wander [1998]).

Fertility	Continuous corn	Corn, Soybean	Corn, Oat, Hay	Treatment mean
	Average corn yield since 1967 (bu/acre)			
Unamended	47.3j[6]	79.4h	100.1fg	75.6D
Manure[1]	82.3h	108.3f	124.4e	105.0C
Manure,PS[2]	92.3g	125.3e	146.7cd	121.4B
U-NPK[3]	127.2e	153.3bc	168.3a	149.6A
M-NPK[4]	141.2de	157.0abc	164.3ab	154.2A
H-NPK[5]	138.8d	160.1abc	160.6ab	153.1A
Rotation Mean	104.9C	130.6B	144.1A	

[1] Manure is applied at 4 tons per acre every year to the continuous corn rotation, whereas 6 tons per acre is applied before corn in the corn, soybean and corn, and corn, oat, and hay rotations. Plant density is 8,000 plants per acre in the manured and unamended plots.

[2] Manure amendment rates are the same as above, plant density is 16,000 plants per acre.

[3] N is applied at 200 lbs/acre urea; plots testing <45 lb/acre of P and 336 lb/acre of K have been amended with 49 and 93 lbs of triple super phosphate and muriate of potash.

[4] Manure and N, P, and K have been applied.

[5] Plots that had received manure until 1967, were amended with only 300 lb/acre of N as urea, and P and K were maintained at test values greater than 112 and 560 lb/acre of P and K.

[6] Rotation by treatment means not followed by the same small letter are significantly different at the 5% probability level. Rotation or treatment means not followed by the same capitalized letter are significantly different at the 5% probability level.

Currently, no-tillage practices are advocated as one of the key means through which soil quality and soil organic matter can be maintained (Karlen and

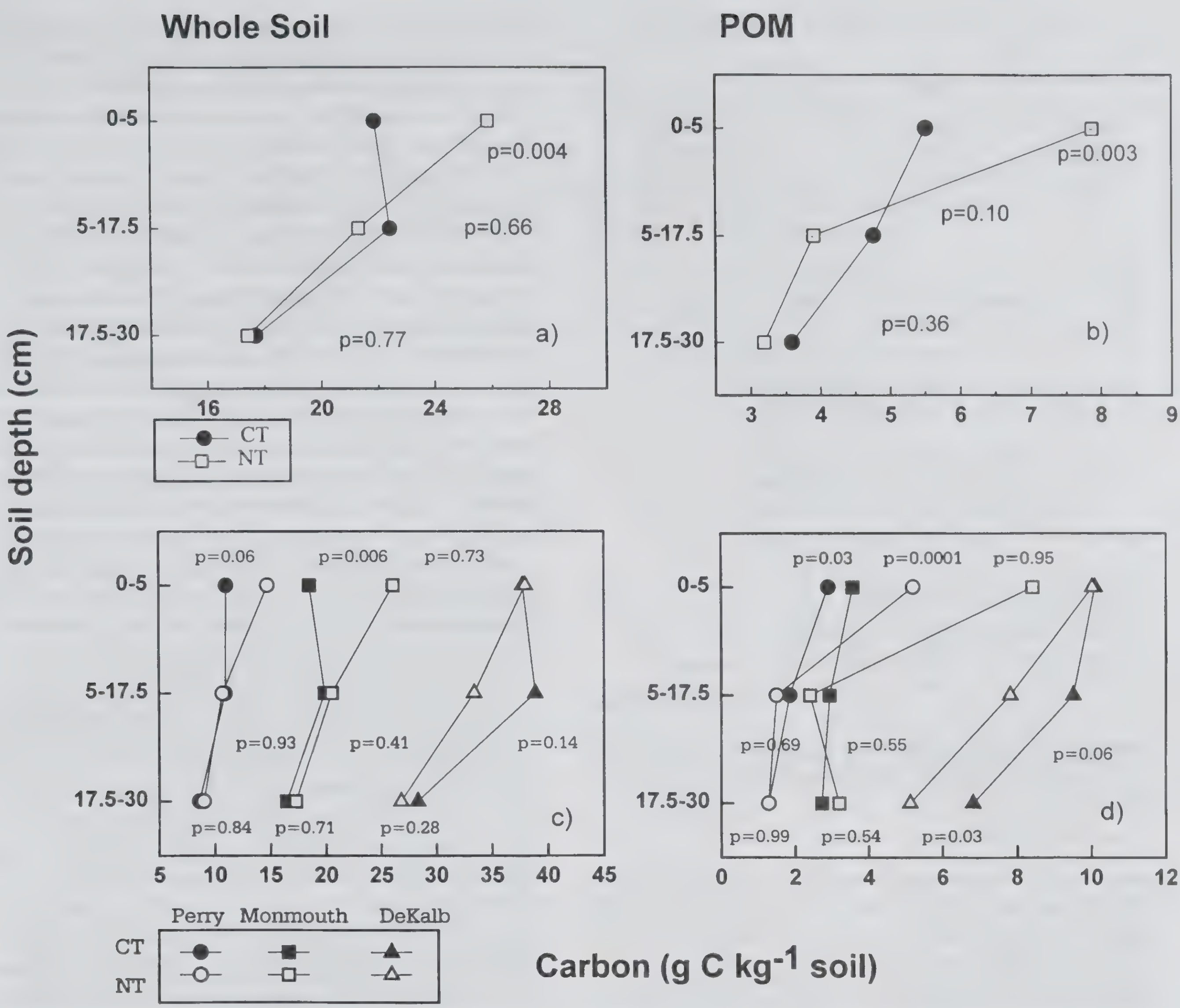

Figure 1 • Conventional (CT) and no-tillage (NT) impacts on the vertical distribution and concentration of carbon (C) in whole soil and in particulate organic matter (POM) averaged over all sites (a and b) and in the Perry, Monmouth, and DeKalb locations (c and d). The p values are within-depth statistical contrasts between tillage treatments.

Cambardella 1996); however, use of no-tillage practices does not increase soil organic matter levels in all soils. The ability of no-tillage practices to increase soil organic matter sequestration has been reported to be limited in poorly drained soils (Paustian et al. 1997), in cooler climates where the impacts of tillage on soil organic matter decay are minimized (Angers et al. 1997), and where erosion rates are low (Alvarez et al. 1998). Relatively little research has been carried out on no-tillage practices in central and northern Illinois because the adoption of these practices has not been widespread until recent years (CTIC 1995). Our recent work suggests that the use of no-tillage practices is generally increasing soil organic matter stratification in central and northern Illinois and that the effects of tillage practices on soil organic matter sequestration are inconsistent (Wander et al. 1998). Soils were collected in 1994 and 1995 from a trial established in 1985 at Perry and Monmouth (Aquic Argiudolls silt loams [sil]), and DeKalb (Typic Haplaquoll silty clay loam [sicl]). Because soil organic matter is a very slowly changing soil property, we used particulate organic matter as an early indicator of change in soil organic matter status. In general, no-tillage practices increased soil organic matter-carbon and particulate organic matter-carbon contents by 25 and 70%, respectively,

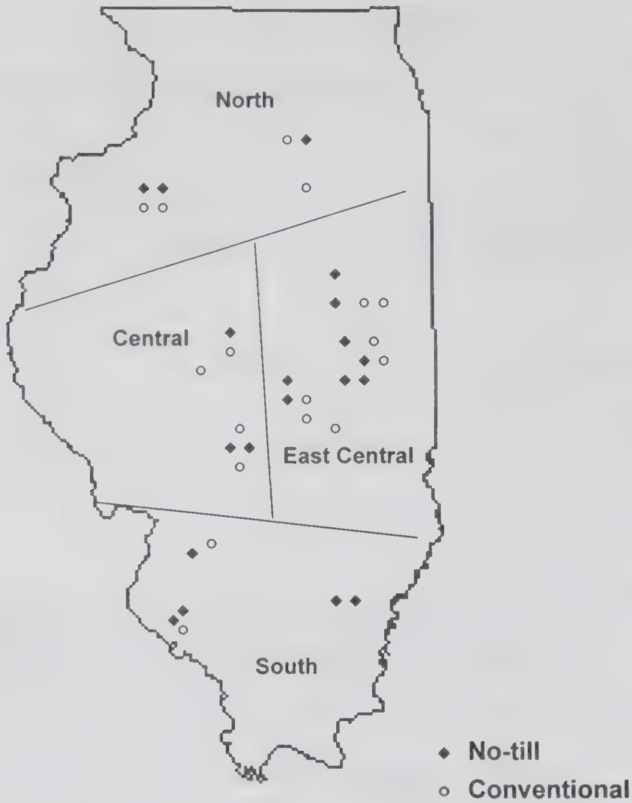

Figure 2 • Map of 16.2-ha farm fields sampled during spring 1995 and 1996; fields were farmed by participants in the Illinois Soil Quality Initiative.

compared with conventional till at the soil surface (0–5 cm) (Figure 1a, b). This was at the expense of carbon at depth (5–17.5cm), which decreased by 4 and 18% in the conventional till and no-tillage soils, respectively. Tillage effects varied among sites (Figure 1c, d). No-till increased soil organic matter-carbon and particulate organic matter-carbon >30 and 100%, respectively, in the top 5 cm of the 2 sil. In the sicl, no-tillage reduced soil organic matter-carbon 14% in the 5–17.5-cm depth and particulate organic matter-carbon over 20% in the 5–30-cm depth.

To determine whether these effects were generally applicable in Illinois, we evaluated tillage and soil-texture impact on biologically active soil organic matter in Mollisols and Alfisols by characterizing particulate organic matter-carbon, potentially mineralizable nitrogen, and the soil microbial biomass (Needelman et al. 1999). Thirty-six fields in Illinois were sampled during spring and summer of 1995 and 1996 (Fig. 2). Each field had been under either conventional tillage (disc, moldboard plow, or chisel plow) or no-tillage management for at least 5 yr. No-till fields contained 15% more soil organic carbon than conventional till fields in the 0–5 cm depth. Tillage did not affect soil organic carbon contents in the 5–15- or 15–30-depths, or in the overall sampling depth (0–30 cm). Fields under no-tillage contained 33% more particulate organic matter and 54% more potentially mineralizable nitrogen in the 0–5-cm depth but there was no impact of tillage on particulate organic matter contents overall (0–15 cm). Average particulate organic matter contents were 29% less in the 5–15-cm depth of the no-tillage than the conventional till soils. The soil microbial biomass did not differ in no-tillage and conventional till systems at any depth. Tillage impacted the vertical distribution but not the total accumulation of biologically active and total soil organic matter. At sand contents below ≈50 g/kg soil, no-tillage fields contained greater soil organic carbon, total N, and particulate organic matter contents in the 0–5-cm depth and lower particulate organic matter contents in the 5–15-cm depth than conventional till fields. In soils with sand content higher than ≈50 g/kg of soil, tillage practices had little impact on the vertical distribution of total soil organic carbon, total N, or particulate organic matter.

The effect of these changes in organic matter on soil quality in the 36 farm fields also was evaluated (Wander and Bollero 1999). Our goal was to determine whether recent adoption of no-tillage practices in the region had generally altered parameters commonly included in the minimum data sets proposed for soil-quality assessment. Samples were collected in 1995 and 1996; in addition, samples were collected from relatively nondisturbed areas adjacent to fields. Tillage or region affected 20 of the 23 physical, chemical, and biological soil parameters characterized. Soil chemical parameters were less variable than biological or physical measures.

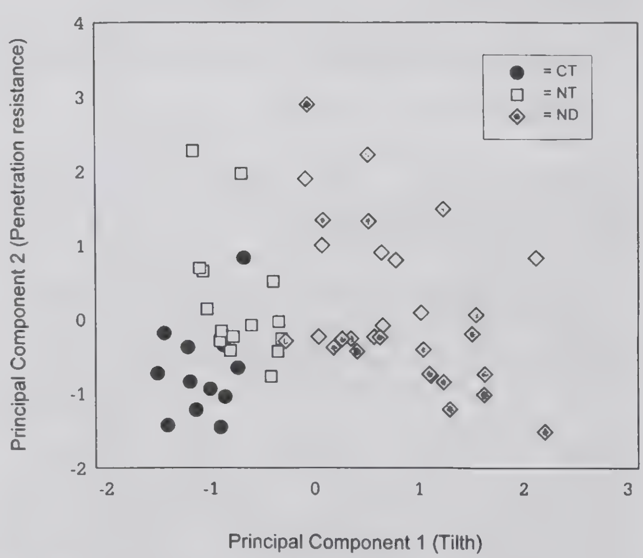

Figure 3 • Tillage effects on the 1st and 2nd principal components.

Principal component analysis was used to assess soil quality overall. Principal component 1 scores, which explained 39% of the total variance of the overall data set, were affected by tillage (nondisturbed areas > no-tillage >conventional till) and increased with particulate and total organic C, total N, biological activity, mineralizable N, and aggregate strength, and decreased with bulk density and dry aggregate size (Fig. 3). The only significant factor contributing to principal component 2 was penetration resistance; principal component 2 explained 13% of the variance and decreased as follows: no-tillage ≥ nondisturbed areas > conventional till. These results suggest that the use of no-tillage practices improved the biological and physical condition of the soil (0–15 cm) despite increased soil consolidation. Tillage choices may result in trade-offs between different soil properties. The results also show that the biological and physical aspects of soils that are influenced by organic matter were the properties most altered by agronomic practices. Particulate organic matter was identified as a promising soil quality measure. Ideally, refinement of soil-quality assessment techniques will help farmers optimize tillage and rotation practices to sustain the productive and environmental filtering capacities of the individual fields they manage.

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LAKE SPRINGFIELD DEMONSTRATION PROJECT

George F. Czapar

The impact of agricultural production on water quality continues to be a major public issue. Best management practices (BMPs) have been shown to effectively reduce pesticide, nutrient, and sediment movement into surface water. The goal of this project is to conduct a 5-yr study to assess best management practice effectiveness on a watershed scale.

Background

National and state monitoring studies of surface water quality have helped identify the most common contaminants, and when they are most likely to occur (Thurman et al. 1991, Taylor and Cook 1995). The extent of pesticide loss from treated fields due to surface runoff can range from less than 1% to >10% of the applied product (Wauchope 1978). Numerous studies have shown that chemical losses are often greatest when heavy rainstorms closely follow pesticide applications.

In April 1994, a 6-in rainstorm in a 24 h period produced considerable runoff and resulted in high levels of atrazine in Lake Springfield. Although treatment with powdered activated carbon (PAC) successfully reduced atrazine concentrations in the finished drinking water, it was an expensive process (Brown et al. 1996). Most would agree that prevention and reduction of risk of pesticide runoff is a preferred approach.

Best Management Practices

Best management practices are designed to minimize adverse impacts on surface water and groundwater quality. In addition to protecting the environment, these practices must be economically sound. Baker and Mickelson (1994) reviewed management factors such as herbicide application and timing, conservation tillage, and filter strips for minimizing herbicide runoff. Hirshi et al. (1997) provided a guide for protecting surface water.

Best management practices that are specific to a watershed are likely to be more effective than treating every acre the same way. In most cases, a combination of practices will be required to achieve water quality goals, and the suggested best management practices may vary depending on soils, topography, and individual farm operation.

Lake Springfield Watershed

Lake Springfield is a 4,200-acre reservoir with a storage capacity of ≈17.5 billion gal of water. It is the public drinking water supply for >150,000 people. The Lake Springfield watershed includes a 265-sq mi area southwest of the lake. Approximately 88% of the watershed's highly productive soils is intensively cropped, with ≈150,000 acres planted each year. Historically, sedimentation has been a concern in the area and was a major reason that a watershed resource planning committee was formed in 1990.

BMP Demonstration Project

The Lake Springfield Watershed project is a collaborative effort involving many different individuals and groups. It includes farmers and landowners; City Water, Light, and Power; the Illinois State Water Survey; the

Natural Resource Conservation Service; Novartis Crop Protection, Inc.; Sangamon County Soil and Water Conservation District; the Soil Tilth Laboratory, USDA–ARS; and University of Illinois Extension.

The specific goals of the project are as follows: (1) to evaluate the effectiveness of best management practices for protecting surface water; (2) to identify combinations of best management practices that can reduce off-site movement of sediments, pesticides, and nutrients; and (3) to provide farmers and landowners a range of alternatives that are both environmentally and economically viable.

Practices such as grass filter strips, riparian buffers, waterways, sediment control basins, conservation tillage, and integrated pest management are some of the possible solutions. Some of these best management practices will be monitored at the field and watershed level.

Project Components

Currently, 13 in-stream automatic samplers have been installed. This sampling network will help to identify vulnerable areas in the watershed and track changes over the course of the 5-yr project. Automatic samplers record stream-flow data during major runoff events, whereas grab samples are periodically collected all year. Water samples are being analyzed for 6 herbicides, nitrate, phosphorus, and total suspended solids.

Working with local farmers, edge-of-field research sites have been established to study specific best management practices and evaluate their effectiveness in reducing soil erosion and surface water runoff. In addition, a network of 55 cooperators throughout the watershed record daily rainfall amounts.

Geographical information system (GIS) and information databases are being created for the entire watershed to assist in data evaluation. Because education is a major component of the project, regular updates and progress reports are provided to farmers, landowners, and the general public. Additional publications, field meetings, and demonstrations will continue over the course of the project.

Summary

The Lake Springfield best management practice project brings together many different groups and organizations that may have individual interests but that all share the common goal of protecting water resources. Because it is being directed at the local level, it relies heavily on the input and involvement of people living in the watershed. The experience and knowledge gained from this project can be shared with other communities in Illinois and across the country.

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AFRAP AND THE LAND APPLICATION RULE: WHERE ARE WE TODAY?

Warren Goetsch

The agrichemical industry continues to evolve as does the industry it serves. Consolidation and mergers seem to be an almost every day occurrence. Just as farms continue to increase in size and decrease in number, so do the various support industries. Retail agrichemical dealerships have experienced these same trends. Concern about the environment and possible impacts of modern production agriculture on the environment also have been key issues during this decade. New laws governing the pesticide registration process and changing requirements for containment structures and systems at retail agrichemical sites have challenged the industry to be environmentally sensitive while remaining economically viable.

The restructuring of the industry, with consolidations, mergers, and realignments coupled with environmental concerns has caused companies to cautiously examine facilities for possible environmental liability before the purchase, sale or the reinvestment in a site. If environmental problems are discovered, what are the appropriate methods to address the contamination? Are there economical approaches to conduct an environmentally responsible remediation activity?

In 1989, the Illinois state legislature partially addressed some of these issues when it provided authority to the Illinois Department of Agriculture to issue written authorizations to the owner or operator of an agrichemical facility for the land application of pesticide contaminated soils at agronomic rates. This authority allowed facilities to "land farm" pesticide contaminated soils originating from retail sites on crop production lands under specific governmental oversight. This helped reduce the cost of a remediation project by avoiding the use of landfills. It allowed the pesticide present in the facility soil to naturally degrade on cropland, just as a pesticide normally applied to farm fields for pest control purposes would degrade during the crop season. Within the past 9 years, the Department has issued over 40 authorizations, allowing facilities to address pesticide contamination at these sites without experiencing the sometimes over- burdensome cost of soil disposal at a landfill. This authority has been amended several times during the intervening years and now allows both soil and groundwater as well as pesticides and fertilizers.

In addition, the state legislature also attempted to examine more closely the types of challenges that exist regarding the nature and extent of agrichemical contamination at these facilities when it mandated the Department to conduct a study of these sites. As a result, in 1995 the legislature again amended the Pesticide Act and provided for the creation of the Agrichemical Facility Response Action Program (AFRAP). AFRAP is intended to provide a voluntary, industry-specific remediation program for agrichemical facilities to be administered by the Department in cooperation with a Governor-appointed Board.

Program Status—Land Application Rule

The land application authorization program has been operating primarily on Department policies since the provisions were added to the Pesticide Act in 1990. In 1997, the Department, in cooperation with the AFRAP Board, began the development of formal rules based on these past policies. The Department formally filed a rulemaking proposal at the end of June 1998. The initial

public comment period ended in August. Since that time, the Department has been evaluating the comments received during the comment period and making adjustments that seem warranted. It is the Department's hope that the updated rule proposal will be re-published by the end of the 1998 calendar year (or soon thereafter), either as a second notice proposal (if the changes to the rule are minor) or as a new first notice proposal (if the proposal is significantly different from the original proposal).

Program Status—AFRAP Rule

The Department and the AFRAP Board have worked jointly on the creation of the program for sightly more than 2 years. The challenge has been to create a program which is both environmentally responsible and economically reasonable. The program must provide similar levels of environmental protection as existing multi-industry programs operated by the U.S. EPA or IEPA while being specific to the agrichemical industry in Illinois. The Department and the Board are attempting to incorporate concepts from other programs while using data specific to the hydrogeology and agrichemical industry of Illinois. A draft rulemaking proposal is currently under development with the hope of making the formal filing sometime in early 1999.

Summary

Both the land application authorization rule and the Agrichemical Facility Response Action Program are intended to provide improved, industry-specific mechanisms for the Illinois agrichemical industry to appropriately address possible pesticide and fertilizer contamination at retail sites across the state. These programs must be environmentally responsible and economically reasonable if they are to be successful. The Department is hopeful that both programs will be fully defined and available for industry use during the 1999 calendar year.

FOOD QUALITY PROTECTION ACT: AMERICAN CROP PROTECTION ASSOCIATION PERSPECTIVE

Ab Basu

Farmers, nurserymen, public health officials, pest control operators and many other businesses that rely upon pesticides are facing the unnecessary loss of valuable products because of the way the Environmental Protection Agency (EPA) is implementing the 1996 Food Quality Protection Act (FQPA).

Problem

The new law substantially changes the way pesticides are evaluated scientifically for their health effects. With no transition time, EPA has the impossible task of re-evaluating more than 9,000 pesticide uses for safety within 10 years, with the first 3,000, including most organophosphate and carbamate insecticides, subject to an August 1999 deadline. EPA is deciding which pesticides and pesticide uses (or tolerances) will remain available and which won't.

Arguing that it must meet the short deadlines imposed by FQPA to set pesticide tolerances, it appears EPA is using unrealistic, theoretical assumptions, rather than real-world data from farmers, businesses, public health officials and others about how they actually use pesticides to protect their crops and us.

Impact

Because EPA is not implementing FQPA fully and fairly, valuable pesticides will be unnecessarily lost, threatening farm production, business operations and public service. For example, able to choose from a wider array of pesticides, foreign growers will enjoy a competitive edge of U. S. farmers. Fewer pest control products will mean less conservation tillage, less Integrated Pest Management and more pest resistance.

Pest control products that keep our homes clean, our hospitals and public buildings free of rats and cockroaches, our parks and golf courses weed- and fungus-free and our rights-of-way safe will be lost.

Solution

FQPA's requirements are strict but achievable, provided EPA:

- allows development of the best scientific data to meet the new safety standards;
- bases pesticide decisions on actual pesticide use, and
- uses uniform policies to implement FQPA.

Benefit: by implementing what Congress intended in FQPA, consumer and environmental protection is maintained and enhanced. Table 1 lists organophosphate and carbamate insecticides in the August 1999 group of pesticides to be reassessed under FQPA. They face immediate unnecessary restrictions and/or cancellation.

What is the Risk Cup?

Enacted in 1996, FQPA contains far-reaching provisions to revise the standards pesticides must meet to be registered by EPA for use. To help understand the

changes brought about by FQPA, think of the exposure that can be safely allowed for a particular pesticide as filling a "risk" cup. This cup contains the amount of pesticide residue that a person can be exposed to daily without affecting health.

Before FQPA

Before FQPA, each pesticide had its own risk cup, which held only the risk from use on food crops; for example, from corn and apples.

"Aggregate" Risk

Under FQPA, the risk cup must now make room not only for residues on food, but also from those found in drinking water, from uses in and around the home, such as on lawns and gardens, and on public spaces, such as parks, rights-of-way and golf curses. Exposure from these multiple sources are combined as "aggregate" risk.

10X Margin

When data pertaining to a pesticide's effects on children's health call for it, EPA also may add an extra tenfold or more margin of safety. In these cases, the risk cup becomes even smaller, resulting in potentially fewer pesticides and/or pesticide uses.

Table 1 • List of Threatened Pesticides

	Major Crop Uses	Registered for Non-Ag Use
Organophosphates		
Orthene, Payload	Cotton, Lettuce, Tobacco	Yes
Guthion, Sniper	Cotton, Apples, Sugarcane	Yes
Lorsban, Dursban	Corn, Cotton, Alfalfa	Yes
D-Z-N, Knox Out, Diazinon	Alfalfa, Lettuce, Corn	Yes
Bidrin	Cotton	?
Cygon	Alfalfa, Cotton, Wheat	Yes
De-syston	Corn, Cotton, Wheat	?
Ethion	Citrus	?
Mocap	Potatoes, Tobacco, Peanuts	Yes
Ethyl Parathion	Alfalfa, Sorghum, Sunflowers	
Nemacur	Tobacco, Cotton, Grapes	Yes
Dyfonate	Corn, Peanuts, Potatoes	??????
Cythion, Malathion	Alfalfa, Cotton, Sorghum	Yes
Monitor	Cotton, Potatoes, Tomatoes	?
Supracide	Almonds, Citrus, Plums	?
Penncap M	Corn, Cotton, Wheat	?????
Dibrom, Legion	Cotton, Grapes, Citrus	Yes
Metasystox R	Cotton, Broccoli, Cauliflower	Yes
Thimet	Corn, Cotton, Potatoes	?
Imidian	Apples, Alfalfa, Potatoes	Yes
Curacron	Cotton	?
Bolstar	Cotton	
Counter	Corn, Sorghum, Sugarbeets	?
Carbamates		
Temik	Cotton, Peanuts, Sugarbeets	?
Sevin	Alfalfa, Apples, Corn	Yes
Furadan	Alfalfa, Corn, Rice	?
Carzol	Citrus, Apples, Nectarines	?
Lannate	Cotton, Sorghum, Peanuts	?
Vydate	Cotton, Apples, Potatoes	?
Larvin	Cotton, Soybeans, Sweet Corn	?

Cumulative Risk

Furthermore, under a concept known as "cumulative" risk, if two or more pesticides act on human health in the same manner, FQPA requires them to share a common risk cup, again shrinking the number of available pesticides and/or pesticide uses.

When applying these new standards, EPA frequently uses the most extreme, unimaginable assumptions; for example, that a farmer drinks directly from a farm pond, filled with runoff from the cornfield and barnyard! Such assumptions ignore real-world data, disregard sound science and make the risk cup artificially overflow. Safety is not enhanced. Valuable pesticides and their uses are lost unnecessarily.

FOOD QUALITY PROTECTION ACT: U.S. ENVIRONMENTAL PROTECTION AGENCY PERSPECTIVE

John Ward

Federal Food, Drug and Cosmetic Act Provisions (FFDCA)

Health-Based Safety Standard for Pesticide Residues in Food: The new law establishes a strong, health-based safety standard for pesticide residues in all foods. It uses "a reasonable certainty of no harm" as the general safety standard, the same approach used in the Administration's 1994 bill.

- A single, health-based standard eliminates longstanding problems posed by multiple standards for pesticides in raw and processed foods.
- Requires EPA to consider all nonoccupational sources of exposure, including drinking water, and exposure to other pesticides with a common mechanism of toxicity when setting tolerances.

Special Provisions for Infants and Children: The new law incorporates language virtually identical to the Administration's 1994 bill to implement key recommendations of the National Academy of Sciences report, "Pesticides in the Diets of Infants and Children."

- Requires an explicit determination that tolerances are safe for children.
- Includes an additional safety factor of up to tenfold, if necessary, to account for uncertainty in data relative to children.
- Requires consideration of children's special sensitivity and exposure to pesticide chemicals.

Limitations on Benefits Considerations: Unlike previous law, which contained an open-ended provision for the consideration of pesticide benefits when setting tolerances, the new law places specific limits on benefits considerations.

- Apply only to non-threshold effects of pesticides (e.g., carcinogenic effects); benefits cannot be taken into account for reproductive or other threshold effects.
- Further limited by three "backstops" on the level of risk that could be offset by benefits considerations. The first is a limit on the acceptable risk in any one year—this limitation greatly reduces the risks. The second limitation is on the lifetime risk, which would allow EPA to remove tolerances after specific phase-out periods. The third limitation is that benefits could not be used to override the health-based standard for children.

Tolerance Reevaluation: Requires that all existing tolerances be reviewed within 10 years to make sure they meet the requirements of the new health-based safety standard.

Endocrine Disrupters: Incorporates provisions for endocrine testing, and also provides new authority to require that chemical manufacturers provide data on their products, including data on potential endocrine effects.

Enforcement: Includes enhanced enforcement of pesticide residue standards by allowing the Food and Drug Administration to impose civil penalties for tolerance violations.

Right to Know: Requires distribution of a brochure in grocery stores on the health effects of pesticides, how to avoid risks, and which foods have tolerances for pesticide residues based on benefits considerations. Specifi-

cally recognizes a state's right to require warnings or labeling of food that has been treated with pesticides, such as California's Proposition 65.

Uniformity of Tolerances: States may not set tolerance levels that differ from national levels unless the state petitions EPA for an exception, based on state-specific situations. National uniformity, however, would not apply to tolerances that included benefits considerations.

Federal Insecticide, Fungicide, and Rodenticide Act Provisions (FIFRA)

Pesticide Reregistration Program: Reauthorizes and increases (from $14M to $16M per year) user fees necessary to complete the review of older pesticides to ensure they meet current standards. Requires tolerances to be reassessed as part of the reregistration program.

Pesticide Registration Renewal: Requires EPA to periodically review pesticide registrations, with a goal of establishing a 15-year cycle, to ensure that all pesticides meet updated safety standards.

Registration of Safer Pesticides: Expedites review of safer pesticides to help them reach the market sooner and replace older and potentially more risky chemicals.

Minor Use Pesticides:

- Establishes minor use programs within EPA and USDA to foster coordination on minor use regulations and policy, and provides for a revolving grant fund to support development of data necessary to register minor use pesticides.
- Encourages minor use registrations through extensions for submitting pesticide residue data, extensions for exclusive use of data, flexibility to waive certain data requirements, and requiring EPA to expedite review of minor use applications. These incentives are coupled with safeguards to protect the environment.

Antimicrobial Pesticides: Establishes new requirements to expedite the review and registration of antimicrobial pesticides. Ends regulatory overlap in jurisdiction over liquid chemical sterilants.

FOOD QUALITY PROTECTION ACT: ILLINOIS FARM BUREAU PERSPECTIVE

Nancy Erickson

The Food Quality Protection Act (FQPA) was passed unanimously by Congress and signed into law by President Clinton in 1996. Since its passage, however, there has not been unanimous support across the nation on the way the act is being implemented.

The FQPA established a new standard for evaluating pesticides based on a reasonable certainty of no harm. It was supported by the Farm Bureau because it promised to achieve many of our pesticide policy objectives. Prior to its passage, the Environmental Protection Agency (EPA) indicated that implementation of the FQPA would not cause large-scale cancellation of products and that the transition to the new law would be seamless. The transition to the FQPA has been anything but smooth.

The purpose of this paper is to provide some background on the FQPA and how it is being implemented and then to outline some of the concerns the Illinois Farm Bureau has with the act and to discuss some possible solutions.

Background

The FQPA was signed into law on 3 August 1996 and amends the Federal Insecticide, Fungicide, and Rodenticide Act and the Federal Food, Drug, and Cosmetic Act. The FQPA replaced the zero-risk Delaney Clause, and it requires EPA to adopt a new process to access pesticides to determine if they should remain on the market. The FQPA states that the EPA must combine the dietary risk from a specific pesticide with the risk from drinking water and residential exposure from that same pesticide. Furthermore, it requires the EPA to combine the risks of multiple pesticides that have a common mechanism of toxicity. The law also places special emphasis on the protection of infants and children.

The EPA uses the analogy of a "risk cup" to demonstrate how they will decide what acceptable levels of risk that a pesticide or family of pesticides can have and still remain on the market. When the risk cup is full, pesticides will be cancelled.

By 3 August 1999, the EPA must evaluate one-third of all pesticide tolerances. The first products to be evaluated are the organophosphates and the carbamates.

The EPA has outlined 9 science policies that they will use to implement FQPA and the tolerance reassessments. These science policies are as follows:

1. Applying the FQPA 10-fold safety factor.
2. Assessing dietary exposure assessment.
3. Analyzing exposure assessment—interpreting "no residues detected."
4. Establishing dietary exposure estimates.
5. Assessing drinking water exposure.
6. Assessing residential exposure.
7. Aggregating exposures from nonoccupational sources.
8. Conducting a cumulative risk assessment for the organophosphates or other pesticides with a common mechanism of toxicity.
9. Selecting appropriate toxicity end points for risk assessment of organophosphates.

Areas of Concern

Much of the problem with FQPA's implementation is that the EPA is using questionable science. The law requires the EPA to use reliable and available data when it assesses pesticides. Because of the August 1999 deadline, the EPA says they do not have enough time to gather all the needed data. As a result, they are incorrectly assuming that farmers use pesticides at maximum rates and that residues remain on foods at maximum levels. If the EPA uses these default assumptions, they will vastly overestimate risks associated with use and farmers will lose pesticides based on incorrect data.

Much of agriculture supports the basic principles of the FQPA: a new safety standard, protecting children, and assessing the risks from aggregate exposures to a single chemical as well as from cumulative exposure to multiple chemicals with a common mechanism of toxicity. The implementation can only work well, however, if reliable scientific data are available and new risk assessment methodologies are adopted.

A critical problem with the EPA's implementation of the FQPA is the agency's decision to rely on unduly conservative default assumptions and safety factors in the absence of real data. The results are risk assessments that grossly overstate risk and unnecessarily threaten the availability of important crop protection products and the health benefits that result from an affordable, abundant, wholesome food supply.

If we lose a lot of pesticides in the United States because of the way the act is being implemented, it will probably result in more food being produced outside the country where foreign growers can still use pesticide products that U.S. producers can no longer use.

The loss of pesticides also may mean increased costs of production, decreased yields, changes in management systems, increased consumer prices, potential adverse health impacts, possible adverse environmental impacts, and increased cost of compliance.

Suggestions for Change

Because of agriculture's concern with the implementation of the FQPA, industry established an Implementation Working Group (IWG) comprised of national agricultural groups, including the American Farm Bureau Federation. The IWC developed guiding principles to help ensure a fair and equitable implementation process. The guiding principles are that the implementation must be based on sound science, transparent, balanced, and workable. The IWG also developed specific recommendations for changing the way the EPA is implementing the law.

1. The EPA must use sound science and reliable information as intended by Congress.
2. The EPA must acknowledge to Congress and to the public that sound science requires accurate data that take time to develop.
3. The EPA must not use unrealistic default assumptions in the tolerance reassessment process.
4. The EPA must determine whether to apply additional uncertainty factors on a chemical-specific, case-by-case basis considering the weight of available and reliable scientific evidence.
5. The EPA must use the most relevant toxicity end points in the tolerance reassessment process.
6. The EPA must establish a deliberate and transparent decision-making process.
7. The EPA must give higher priority to making sound scientific decisions than to completing final tolerance reassessments by statutory deadlines.
8. The EPA must revoke only those tolerances that pose actual unacceptable risks.
9. The EPA must not revoke tolerances unless tolerance reassessments are based on credible use information.
10. The EPA must propose policies and methods for risk allocation and make them available for public review and comment.
11. The EPA must allow time for pesticide users to make a responsible transition to alternative products.
12. The EPA must address the current resource imbalance between tolerance reassessment and new chemical or new use registration, and they must accelerate the pace of making decisions on new products.

Recent Direction

Because of concerns expressed on the way the FQPA was being implemented, Vice President Al Gore wrote a memo to the EPA and the United States Department of Agriculture (USDA) stating that the act should use sound science, be transparent, have a reasonable transition for agriculture, and involve consultation with the public.

Also, the administration established a national Tolerance Reassessment Advisory Committee (TRAC), which has been meeting since last summer. The committee, with members from all sectors affected by pesticides, including agriculture, is looking at how the FQPA is being implemented. The work of the committee will continue until late this spring. It will be focusing on the 9 science policies the EPA is using to implement the FQPA. The TRAC has helped to make the process the EPA is using somewhat more visible and open to comment.

In June 1998, Congressman Ray LaHood introduced a nonbinding sense of the Congress resolution calling for increased congressional oversight of FQPA implementation. The resolution asked that the FQPA be implemented using the 4 principles of the Vice President's memo to the EPA and the USDA. The Farm Bureau and much of agriculture supported this resolution.

Summary

The creation of the TRAC and these other commonsense documents makes it appear as if the negative direction the EPA was taking in implementing the FQPA has changed. We should not be lulled into thinking that this positive direction will continue. The Farm Bureau still has many concerns with the final outcome of issues related to the act. There are many key decisions ahead of us regarding FQPA and these decisions will determine the viability of Illinois and U.S. agriculture. It will be necessary for agriculture to continue working together to ensure the act will be implemented in a way that echoes the original intent of Congress.

FOOD QUALITY PROTECTION ACT: UNIVERSITY PERSPECTIVE

Allan S. Felsot

The Saga of the Food Quality Protection Act (FQPA) Signals the Loss of University Relevance

I have a sense of deja vu. Not since *Silent Spring* gathered steam have growers and the agricultural chemical industry been more embattled. The FQPA took everyone by surprise. On the surface it looked to be a sweet deal with bipartisan support. For the agricultural community, it turned out to be a Trojan Horse. *Silent Spring*'s diatribe against DDT took years to embroil the public, finally leaving in its wake a bristled sensitivity to chemical technology that belies a much improved quality of life since World War II. In one stealthy blow, the FQPA quickly changed the regulatory landscape in which agriculture must play.

For me, the reverberations of the FQPA have begun to resemble a saga where the protagonist's whole life is revealed slowly as he tries to figure out whether he is exercising free will or is a victim of some cruel fate. I analogize the university today to that protagonist. But in contrast to the romantic hero, who at the end takes charge of his life, the university, seems to have fallen from grace as leader into oblivion as follower over the bridge into the 21st century.

My colleagues will think me harsh. After all, what professor does not want to see himself or herself as doing cutting-edge research. But the landscape has changed, and the ideas of the university are no longer setting the agenda for the agricultural community. On the issue of the FQPA, especially, I've slowly realized the university has become less relevant.

A Legacy of Innovation

What a shame, this loss of relevance. The issues raised by the FQPA were ideas that the land-grant universities tackled years before public policy took notice. For example, do you not wonder where Rachel Carson got her ideas? Turn to the back of *Silent Spring*, and you will see references to scientific publications penned by tens of scientists from land-grant universities 10–15 yr previously. The conundrum posed by the broad spectrum DDT—insect resistance, wholesale slaughter of insect natural enemies, and explosions of secondary pests—were the real ecological problems perceived by entomologists long before *Silent Spring*. Only a few years after DDT's wide-scale commercial introduction, land-grant-university scientists perceived the problems. Responding as leaders, they conceived of the integrated control concept.

Long before DDT was finally banned in 1973, land-grant-university scientists already had integrated pest management (IPM) philosophy, the child of the integrated control concept, waiting in the wings. Think of the IPM tools land-grant scientists brought to bear on the problems of pest control. Entomologists were viewing agricultural fields as bona fide ecosystems. To understand effective but environmentally compatible methods of pest control, entomologists were developing insect life tables and sampling theory, and modeling population dynamics. Entomologists were bending over backwards to make chemical pesticides a last resort, and in the interim, learning how to use pesticides more compatible with the natural regulatory forces of the agroecosystem. All this activity happened years before the sustainable agriculture movement.

Universities Have Been Edged Out by New Players

Over the last 10 yr or so, university leadership has diminished to the point where institutions are reacting rather than leading. The FQPA really shows just how far out of the loop the universities have become. But it's not for lack of skill, desire, or motivation. No, it's more a case of leadership being transferred to private industry, consultants, and nongovernmental organizations and advocacy groups (NGOs). But most of all, leadership has been shifted to the burgeoning regulatory agenda of the Environmental Protection Agency (EPA), where risk management is forcing changes in agricultural technology, justified or not.

What evidence motivates this lamentation? I recently read in *Chemical & Engineering News*, the weekly trade magazine published by the American Chemical Society, that two large chemical companies were merging their interests in biotechnology to develop new cultivars of wheat. I thought about my own academic department in its crumbling building, with increasingly outdated equipment, flagging student interest, and dwindling numbers of technicians. I wondered, how can we compete? What do we in universities have left to offer a revolutionized chemical industry that no longer considers itself producers of chemical products as much as inventors of life science technologies?

The EPA is using the FQPA as a wedge to drastically reduce if not eliminate organophosphate insecticides in favor of "reduced risk" pesticides, however that epithet may be defined. Lists of these alternatives are being published by NGOs, as if they're off-the-shelf products and ready to go. Yet, the few existing alternatives fitting the reduced risk model are the brainchild of industry. Examine the revolution in weed control, so important to the success of Corn Belt crops. Sulfonylurea and imidazolinone herbicides offer pest control at fractions of the rates of the triazines and the chloroacetanilides. These compounds are less toxic than table salt, noncarcinogenic, lack effects on the endocrine system, and are generally short lived in the environment.

Ask yourself, what sector of our economy has the lead in developing the use of genes as pest control products? Industry is already far ahead of the universities, realizing that genetic engineering for pest control will soon plateau while engineering for value-added qualities will rise exponentially just a short time beyond the millennium. Meanwhile, the university laboratories dedicated to the agricultural sciences grow more antiquated. How easy has it been for university researchers in facilities opened only 5 yr ago to keep up with the latest advances in instrumentation?

Historically, university agricultural scientists were in the vanguard of developing and studying new crop production and protection techniques. Growers have always been innovators and welcomed the university as partners. Today, however, I see more grower dissatisfaction with universities, and a perception has developed that academic institutions are more interested in accommodating the interests of Federal policy makers rather than the rural community. Growers see the FQPA as another attempt to control their economic livelihood, and are looking to the universities for help, but thus far have had to take matters into their own hands. In the northwestern United States, for example, minor crops account for the majority of aggregate farm receipts. The growers themselves are pushing the EPA to ensure that its regulatory decisions are informed by sound science. The growers are the most vocal advocates of more research because they are worried that EPA will remove essential crop protection chemicals without due consideration to the lack of available alternatives.

Public Perceptions and Politically Correct Solutions

Despite the many years of effort by university scientists involved with crop protection to develop IPM and weave it into the sustainable agriculture philosophy, the agricultural community is beset with a public perception that their methods are broken. Worse, the methods are perceived as causing an unprecedented health crisis. Rachel Carson and *Silent Spring* have been reincarnated as Theo Colborn and *Our Stolen Future*. In writing the forward to *Our Stolen Future*, the Vice President has given more credence to the ideas in one book than to the years of university research. Our policy makers seem swayed by every new Environmental Working Group report concerning the dangers of pesticides on children. The rhetoric has gone beyond pest control to questioning the safety of fertilizers, already motivating at least one state to pass new regulations. And where are the universities in this debate?

If the universities aren't already left in the cold, they soon will be. In one sense, the universities are their own problem. Instead of vigorously defending the science behind agricultural technologies, they rush to change the names of their departments and colleges to politically correct euphemisms. Instead of defending the plodding, but meticulous combination of basic and

applied research started long before Rachel Carson and still evolving, they become whiplashed by popular notions of sustainable agriculture espoused by policy makers who have never been outside their cozy little urban enclaves. Instead of supporting the excellent scientists already on hand with hard funding of technical support and routine upgrading of instrumentation, administrators have stretched resources thinner and thinner with new faculty, new programs, and new buildings.

How can universities get back into the game and help the growers overcome the albatross of the FQPA. A complementary question is what is the proper role of the university regarding implementation of the FQPA.

What Should Universities Be Doing?

How can universities get back into the game and help the growers overcome the albatross of the FQPA? A complementary question is what is the proper role of the university regarding implementation of the FQPA?

I believe the university should reiterate its claim on two roles. First, the university must do what it exists for—skeptical inquiry. Second, the university must continue to do what it had started before *Silent Spring*—develop, validate, defend, and promote crop protection systems within the context of risk management goals.

Both roles require the understanding of the distinctions between risk assessment and management. Risk assessment involves hypothesis testing to generate answers to a variety of questions about a chemical or technology. How toxic is pesticide X? What dose corresponds to the no observable effect level (NOEL)? What is the exposure of children, adults, and workers in the food supply?

Risk management belongs in the realm of policy. Once answers are generated, and estimates of risk or probabilities of harm are calculated, then regulatory agencies, representing the public, must decide how to manage the risk or whether it is even worth it. In a democratic society, management is as much or more influenced by politics and economics as by the scientific "facts."

One of the problems that policy makers have with scientists is our uncertainty. We shy from making broad absolute statements, preferring to hedge our bets until another experiment is run. Thus, under pressure to react to perceptions of risk, policy boldly moves ahead of scientific timidity. Then policy becomes an end onto itself, perpetuating misconceptions that subsequent scientific studies may deflate. After nearly 50 yr of ever more sophisticated toxicological testing, perhaps it is time for university scientists to be much more confident in their public pronouncements.

Applying Skeptical Inquiry to the FQPA

Here are examples of skeptical inquiry regarding the FQPA. One of the primary motivations for changes in pesticide law was the notion that the current regulatory system failed to protect infants and children. The myth was promoted by the Natural Resources Defense Council (NRDC), an NGO specializing in environmental advocacy. The NRDC published *Intolerable Risk*, a 1989 report that generated the Alar scare once CBS News publicized it. Buried in the report, however, was the conclusion that hundreds of thousands of children are exposed to organophosphate insecticides at levels 500 times greater than the acceptable daily intake (ADI). The NRDC rightly pointed out the physiological differences between infants and adults, and more importantly key differences in dietary habits. The NRDC provided no credible evidence, however, that pesticide residues in food were more hazardous to children. Furthermore, their conclusion that children were being exposed to levels of organophosphate insecticides above the ADI was based on faulty calculations.

Where were the universities in analyzing the NRDC report through appropriate skeptical inquiry? Instead, the report, unchallenged by academia, was accepted by the public, hook, line and sinker.

A year prior to the Intolerable Risk report, Congress had asked the National Research Council (NRC), the research arm of the National Academy of Sciences, to investigate whether regulations were adequate to protect infants and children. The result of the investigation, published in 1993, was *Pesticides in the Diet of Infants and Children*. This NRC report did what the NRDC report failed to do. It motivated the fundamental changes to pesticide regulations born in the FQPA. The most fundamental changes, as mentioned previously, were increased scrutiny of risks to infants and children.

The FQPA also incorporated many of the ideas regarding endocrine-system-disrupting chemicals engendered by *Our Stolen Future*. Infants and children are perceived as being at greatest risk from chemicals that could mimic natural hormones. Circumstantial evidence has implicated research from Tulane University as influencing the eagerness to place into the law provisions for endocrine-disrupter screening. An EPA administrator noted the research report with great public consterna-

tion. The Tulane scientists professed to shown for the first time that several pesticide combinations were synergistic in their endocrine-disrupting potential. The FQPA was passed two months after the research was published. One year later, the Tulane research was publicly retracted because the experiments were not repeatable in its own laboratories nor anywhere else. Little publicity accompanied this embarrassing incident, and EPA policy was not swayed.

No self-respecting toxicologist would shy away from testing every imaginable aspect of pesticide effects during product development. But that testing was conducted prior to FQPA, and has been continued with new toxicological methodologies. Numerous toxicologists are dismayed at EPA's perception that we are in some kind of crisis regarding children's health and pesticides. Lack of university involvement in analyzing and interpreting all the reports, whether they be government, NRC, or NGO, allows perpetuation of the myth that children are currently being harmed from pesticide residues in food and the environment. A skeptical inquiry of the NRC report alone would reveal what the academy really said about pesticides and children.

- "Differences in toxicity between young and mature animals may be in either direction but are generally modest."
- "Data on age-dependent pharmacokinetics of pesticides are lacking for most animals, and the database on pharmacokinetics and metabolism of drugs in immature humans also is limited."
- "On the basis of our understanding of mechanisms of action of toxicants in mature animals, including the human adult, it is generally possible to predict that similar mechanisms of action will occur in immature animals, including the human infant, child, or adolescent (i.e., biochemical mechanisms of toxicity are similar across age and developmental stages)."
- "Studies in laboratory animals have demonstrated an age-related difference in acute toxicity; however, the direction of the difference is dependent on the chemical, and the magnitude of the effect is usually no more than 1 order of magnitude and often is considerably less."
- "Rodents are less mature at birth than humans. Thus, more pronounced age-related differences would be anticipated in rodents than in humans during the neonatal period."
- "Very few data were found on the relative toxicity of pesticides in immature and mature humans."

The NRC report did try to make a case that infants are at greater risk for acute toxic effects of pesticides that are cholinesterase inhibitors (the mode of toxicity of the organophosphate insecticides). This conclusion was based on worker exposure studies, not food residue levels. Indeed, the NRC stated, "Generally, data are insufficient for evaluation, and determination of the neurodevelopmental effects for low-level exposure is not possible using current data." Everyone agrees more data will improve risk assessment, but that is not qualitatively the same as concluding that children are at greater risk. In fact, in recently released risk assessments, EPA has concluded that most of the 40 principal organophosphate insecticides show no evidence of causing enhanced neurodevelopmental or reproductive toxicity to neonatal rodents.

The idea that the pre-FQPA provisions did not protect children may have been vastly overstated. Why did universities not step forward to point out the use of uncertainty factors to adjust the NOEL to the Reference Dose (RfD), EPA's equivalent of a safe dose. The uncertainty factors applied a 10-fold factor to account for animal to human extrapolations (in case animals are less sensitive than humans) and another 10-fold factor to account for susceptibility differences between adults and children, the elderly, or the sick. Yet, the perception persists that children have enhanced susceptibility to the toxic effects of organophosphate insecticides and the laws do not protect them. Such perceptions will persist until universities better play the role of skeptic and more effectively communicate in an accessible manner the secrets of the risk assessment process.

Taking on the Challenge of Validating Risk Management

University scientists can act to use their collective research to blaze a new trail for growers when the data warn this course is appropriate. For example, agricultural scientists in the 1950s observed and reported the real ecological problems of DDT— development of insect resistance and explosion of secondary pest populations. University scientists and extension personnel were instrumental in helping wean growers from the use of DDT because it was in the best interest of agricultural production.

As skeptical as I am about the concerns over organophosphate insecticide residues in food, I admit that organophosphate insecticide use will one day be history in the United States. Now universities must step forward to help growers move away from organophos-

phate insecticides to alternative products and pest control strategies. In regions of the United States where minor crops rule, however, and insect control alternatives are practically nil, organophosphate insecticides of one kind or another will remain well into the new millennium. Unfortunately, alternatives were needed yesterday to help solve the FQPA squeeze placed on our growers. Thus, the universities must take the leadership in helping assess the alternative pest control techniques.

Here are some challenges for university researchers. The EPA has been saying there are alternatives to the organophosphates. One recently released NGO report, *Worst First: High-Risk Insecticide Uses, Children's Foods and Safer Alternatives*, by Charles Benbrook, lists for different crops tables of reduced risk pesticides, bio-based alternatives, and bio-based IPM practices. Is anyone in the universities going to assess the validity of this report? I urge all pest control researchers to take a close look at this report. Sponsored by Consumer Union, the publishers of the very well respected *Consumer Reports*, the report is likely to garner enough public pressure to make EPA act swiftly on organophosphate insecticide reregistration decisions.

The agricultural experiment stations need to coordinate their efforts in responding to the lists of organophosphate insecticide alternatives. The alternatives also have risks as well as benefits. For example, if pyrethrins are chosen to replace an organophosphate insecticide, how many applications will be needed in a season on an orchard crop? Would beneficial insects be affected by an increased number of applications? Would there be enough stocks of alternative pesticides to treat minor crops having large acreage (e.g., apples and potatoes). What will be the cost compared with the conventional organophosphate insecticides? Can growers afford the alternatives?

Conclusions

The overshadowing of agriculture by the FQPA shows how universities have lost leadership in agricultural technology. The chemical industries are evolving into life science companies bringing to market reduced-risk pest-control technologies developed solely in their own laboratories. The NGOs have a tremendous influence on public policy. The EPA is using the FQPA to force growers away from organophosphate insecticides. Unfortunately, alternatives are few and of questionable utility at this time. Nevertheless, universities do have a role to play in implementing the FQPA. First, universities must bring skeptical inquiry to bear on the premises behind risk management. No credible evidence exists that supports a crisis in children's health from exposure to currently registered products. Although there can be many long-term benefits to pest control by eschewing organophosphate insecticides, alternatives may not be feasible for minor crops at present. The second role of universities, therefore, involves helping growers make the transition to alternatives. The transition will require time and money. A line has been drawn in the sand. Will universities work together to meet the challenge?

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Program
January 5 and 6, 2000

Wednesday, January 5

Illini Rooms

9:30 a.m.	Welcome, Opening Remarks, and Informational Items, Kevin Steffey

Keynote Session: Agriculture and Crop Protection in the Next Millennium
Todd Gleason Presiding

9:40	Agriculture Management in the New Millennium, Joe Hampton
10:05	New Dimensions in Agriculture: Challenges and Rewards, William Kirk
10:30	Agriculture and Crop Protection at the Onset of the New Millennium: The University's Role, Steven Pueppke
10:55	Knowledge Creation and Tomorrow's Agriculture, Steven Sonka
11:20	Who's Driving the Bus? A Farmer's View of the Next Century, Doug Wilson
11:45	Questions and Answers
12:00	Lunch

Weed Management Issues
Dale Baird Presiding

1:15 p.m.	UFOs in Illinois Soybean Fields, Loyd Wax
1:30	Balance: What Tilted the Scales in 1999?, Christy Sprague
1:45	Biology of and Methods for Controlling Palmer Amaranth, Michael Horak
2:00	Duration of Weed Competition in Roundup Ready Crops, Dan Parker
2:15	Burndown Application Timings in Roundup Ready Soybean, Andy Knepp
2:30	Weed Management Systems in Roundup Ready Soybeans: Is Roundup the Only System? Bryan Young
2:45	Weed Control in Soybeans with Valor, Sarah Taylor-Lovell
3:00	Balancing the Dual Axioms of Weed Control: Topnotch Approaches for Harnessing Grasses and Surpassing Control on the New Frontier, Bill Simmons
3:15	All Right or What's Left? A Weed Scientist in Transition, Marshal McGlamery
3:30	Break

New Developments from Industry
Bill Garver, Jr., Presiding

3:45	DuPont
3:55	BASF
4:05	Monsanto
4:15	Zeneca
4:25	Dow AgroSciences
4:35	American Cyanamid
4:45	Bayer
4:55	Valent
5:05	FMC
5:15	Novartis
5:25	Rhone-Poulenc
5:35	AgrEvo
5:45	Adjourn

Mixer

5:45 to 7:00 p.m.	Illini Union Ballroom *This mixer is sponsored by the Illinois Fertilizer and Chemical Association, and it is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.*

Thursday, January 6

Illini Rooms

Insects—Past, Present, and Future
Dennis Bowman Presiding

8:30 a.m.	Should We Expect More from Wireworms, White Grubs, Grape Colaspis, et al. in the Future? Kevin Steffey
8:45	Management Options for the Southwestern Corn Borer, Phillip Sloderbeck
9:00	Western Corn Rootworms in Soybeans: Is an Adjustment in the Economic Threshold Necessary? Susan Ratcliffe

9:15 Management of Insect Pests During the Past 50 Years: Lessons Learned, F. Tom Turpin

Regulatory and Best Management Issues
Gerald Kirbach Presiding

9:35 Pesticide Misuse in 1999 and Guidance for 2000, Gerald Kirbach

9:50 Illinois' Perspective on Total Maximum Daily Loads (TMDLs), Bruce Yurdin

10:05 Land App and AFRAP—The Rest of the Story, Warren Goetsch

10:20 You've Got Mail! The Consumer Confidence Reporting Requirement, A. G. Taylor

10:35 Results of a Dealer Survey Regarding Best Management Practices, George Czapar

10:50 Break

Genetically Engineered Crops—Status and Issues
Lex Bledsoe Presiding

11:05 Making Sense in Confusing Times: Crop Variety Choices, Emerson Nafziger

11:20 Of Monarchs and Men: Reflections on Bt Corn for 2000, Marlin Rice

11:40 Status of Transgenic Crops for Control of Insects Other than European Corn Borer, Kathy Flanders

11:55 Prescriptive Use of Transgenic Hybrids for Corn Rootworms: An Ominous Cloud on the Horizon? Michael Gray

12:10 p.m. Lunch

Climate, Digital Images, and Plant Disease Management Issues
Dennis Epplin Presiding

1:15 p.m. Global Climate Change: What Will It Mean for Illinois? Ken Kunkel

1:35 Using Illinois' Digital Imaging System to Diagnose Your Plant and Pest Problems, Dennis Bowman

1:50 Chemical Control of Wheat Scab—Problems and Progress, Marcia McMullen

2:10 Sudden Death Syndrome—What's Next? Glen Hartman

2:25 Soybean Cyst Nematode Update—Races and Resistance, Greg Noel

2:40 The Genetics of Gray Leaf Spot Resistance, Mike Clements

2:55 Recovery Time: Herbicides and Interactions with Diseases (Objective IV—IL/IA Yields Project), Wayne Pedersen

3:10 Adjourn

Program Participants

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Agriculture Management in the New Millennium

JOE HAMPTON

Notes:

New Dimensions in Agriculture: Challenges and Rewards

WILLIAM F. KIRK

I am excited about participating in this keynote session about agriculture and crop protection in the new millennium, and it is always a great pleasure to be back in Illinois. We have a unique opportunity to share our views about why crop protection and the entire agriculture industry is one of the most challenging and exciting industries in the world today. As everyone knows, we are facing the toughest agricultural economy in 20 years, with weak demand from major export customers, depressed livestock prices, and record-low crop prices.

We are all redefining our businesses to adapt to the rapid changes in our marketplace – looking for ways to capitalize on new technology, catch the "wave" of a new trend, respond to consumer needs, and develop business partnerships along the value chain from the farm to the table. Our journey into the new millennium surely will present both challenges and rewards.

Transforming the world's food supply by building the systems to ensure the quality and quantity of nutrition per acre is a massive undertaking. However, agriculture is no stranger to change. Production agriculture has been shaped by scientific breakthroughs that have brought hybrid seed, synthetic fertilizer, and sophisticated crop protection chemicals to the farm. But today, we are standing at the threshold to a new age of agriculture, the dimensions of which are only beginning to be appreciated.

Company Direction

DuPont is a science company. We bring science to the market in ways that help make people's lives better. We will soon celebrate our 200th birthday. As the world has changed, the company has reinvented itself for each era. Our founder moved to America and, in 1802, began making black powder to support a nation that was striving to expand and develop, as well as to protect itself. As we moved toward the 20th century and into an industrializing world, the company expanded from explosives into diversified chemicals and polymers. And now, we are transitioning to another new curve for the 21st century – one based on biology and knowledge intensity.

At the same time, the fundamentals that make up our genetic core remain the same. We continue to focus on basic human needs, such as food and shelter, and we continue to use science as a source of solutions to the world's difficult, high-value problems. We want to improve the quality of life for people around the world through enhanced value and renewable resources. We will accomplish this mission only if we work in partnership with those who produce the crops and with other partners along the agricultural value chain from farm gate to dinner plate.

We try to be a company that offers dramatic improvements in people's lives through science-based solutions that make a difference. We want to be viewed as a dynamic company that is on the move, able to foresee and meet future human needs. That is why we have adopted "The Miracles of Science™" as our new corporate theme.

Within our Agriculture, Nutrition & Seed businesses at DuPont, crop protection chemistry remains solidly in our long-term plans. We suggest not only that there are great opportunities for safer, better, and more environmentally benign products but also that there is a responsibility for the leaders in this industry

to continue to renew these critical tools for protecting crops. We intend to continue bringing new chemical technology to the global marketplace.

Historic Perspective

Before looking ahead at how our industry is changing, I think it is helpful to start with a brief historic perspective. Since the turn of the century, and especially in the past 50 years, farming productivity has increased tremendously with a payoff in the form of increased quantity and quality of food. Technological improvements tend to come in waves. These technologies have been geared toward boosting farm productivity, which has improved farmers' bottom-line profits – although not enough in today's climate – and has improved both the quality of life for farmers and the nutrition and affordability of food for consumers.

Technological evolution and constant product displacement have been a fact of life on the farm as new and better technology-based products have been developed. But in the past, the impact of new products on the marketplace typically has been evolutionary and product displacement has generally been gradual. Farmers have had time to integrate new technologies into their cultural practices and to respond to market conditions. Companies have had time to reposition themselves, reformulate their business strategies, and readjust business structures to bring new technology-based products to the marketplace to remain competitive.

The first wave of technology led to the mechanization of the farm. In most areas, the farmer's dependence on hand labor was significantly reduced and productivity increased correspondingly. Mechanization of the farm resulted in a quantum leap in the quantity and quality of the food that farmers produced.

The second wave of technology focused on chemistry – synthetic fertilizers and crop protection products. Fertilizers increased yields and crop protection products helped farmers cut crop losses due to weeds, disease, and insects. By most estimates, as much as 40% of the world's food would be lost without the informed use of crop protection products.

Today, a third wave has formed – based on biotechnology and information technology – and this wave promises to be revolutionary. With biotechnology, we are able to apply the newest and most advanced tools to help plants do things they could not do before. Information technology is taking learning cycles to even faster speeds. Researchers are able to distill insights from mountains of data and immediately reapply that knowledge to continue pushing the frontiers of science. The technology is infiltrating all aspects of agriculture, from the laboratory to the loading dock, and will help us improve food quality, safety, taste, nutrition, cost, and convenience.

Third Technology Wave

This third technology wave is bringing about five fundamental changes in production agriculture. The first is biotechnology, which will drive a systems approach to crop protection. It will push integrated pest management to entirely new levels by continuing to enable us to build more and better crop protection tools into the seeds. Farmers will have opportunities to attack problems from several angles, and they will be optimizing many factors as they make decisions. To keep up with nature's constant flow of new challenges, farmers will need all the tools in their toolbox – genetic, chemical, and cultural practices. And they will need our clear and honest guidance on how to integrate them into their systems.

Second, biotechnology will continue to revolutionize farming as it paves the way for an era of crops with specific, value-adding traits. Agricultural commodities are going to be replaced by specialty products – genetically tailored crops that fill specific end-user needs and generate premium value in the marketplace. Products such as a corn for poultry producers with balanced amino acids for rapid, efficient gains, and high available phosphorous to minimize environmental impact from the manure will become common. Similarly, a corn for swine feeders will provide a different balance of energy level, digestibility, and amino acids. There are two big opportunities for agriculture to grow into. One is the health segment. Soybeans with certain isoflavones will reduce cancer risk and heart disease. The second is sustainable/renewable manufacturing. An example is 3G, which is made from corn and used to make a new polyester with special functional characteristics.

Last year, a story in *The Wall Street Journal* said that in a few decades 75% of the food that we eat will come from genetically engineered crops, which will make the Industrial Revolution pale in comparison. Our industry is targeting growth opportunities for value-added products from segments of the feed, food, and fiber chain, including crop protection traits, crop

quality traits, agronomic improvements, and industrial applications. The market potential is at least $500 billion compared with $30 billion currently for crop protection alone, so the opportunities are large and the impact will be felt at the farm gate.

Third, we will continue to develop and market technologies that benefit people throughout agribusiness from farmers to the ultimate consumer as the influence and desires of the end user become more prominent. The growing availability of proprietary value-added crops will create a paradigm shift at the farm level, significantly altering the role that farmers play and the options that they have in the agricultural production system. The shift in the production system from a supply- to a demand-driven system will result in growing influence on production by the end user. And, it will bring the development of new supply structures, which will enable the farmer to link more directly with his or her end-user customers. Production and marketing of farm produce, particularly corn, soybeans, and wheat, will change dramatically and, with it, the forces that currently shape the production decisions for farmers will change.

Fourth, the pervasive influence of information technology is changing everything we do, but we have not begun to appreciate the impact knowledge will have on agriculture and specifically on our crop protection industry. We are seeing a move toward precision agriculture – farmers are now able to monitor performance and make management decisions on a 10-m^2 grid inside their fields. Specificity will enable improved production efficiency and effectiveness. Connecting that data to the same data for all other producers, and being able to mine it for insights, will significantly shorten learning cycles for farmers. Most farmers have said that they can run 40 or perhaps 50 "experiments" in their farming careers. Information technology is creating a "living laboratory" enabling many experiments every season.

The Internet is also promising, or threatening, to change how commerce is done and how inputs on the farm are purchased. How will farmers' purchase patterns change? What new influences will impact their decisions? What impact will this emerging pattern have on competition and prices, on product stewardship? How it will play out is far from clear. However, we can expect that on-line purchasing will become commonplace in agriculture and will drive efficiency and transparency into our business.

But the real impact from information technology is not going to come from the individual applications within one step in the food and feed value chain such as precision farming or Internet purchases of crop protection products. Instead, it is going to come through the integration of all the steps along the chain. For example, when the product-tracking capability in our industry is connected to global positioning equipment on the sprayer, it will track not only who purchased the product but also precisely where and when it was applied. And soon, the crop in that same field will be traced, through identity preservation systems, from the farm to the end user of the grain and history of the products used to protect it. That information will enable the participants in that whole system to optimize it – to orchestrate the elements in a way that maximizes value.

Finally, a fifth point is the amazing speed of change. Everywhere we look, we see an "explosion of knowledge." Step changes are measured now in months, not in decades. The powerful combination of biotechnology and new information technologies is creating exciting growth opportunities for farmers and for those companies in the agriculture production and distribution infrastructure that are prepared to step up and compete at a new level. And, it is happening at break-neck speed.

In my view, the changes in agriculture over the past 200 years will be dwarfed by the changes that will take place during the early part of the 21st century. The combined impact of biotechnology and information technology to agriculture will rank on the commercial "Richter" scale along with major transforming technologies such as the transistor and the computer. It is truly exciting to be part of such a dramatic retooling of agriculture and the food supply chain. This retooling holds great promise for meeting the challenge of increasing this planet's capacity to increase the food supply by 60% in the next 25 years, in a sustainable way, without an increase in arable land, to feed an expected 8 billion people.

Antibiotechnology Movement

All this change is not without its challenges. There is growing public concern with the use of genetic enhancement, particularly as it relates to food. This public concern has been aggravated by the perception that we in industry have often acted as though public fears are not legitimate and are the result of ignorance.

Whether or not this perception is real, the point is that we in industry must do a much better job of engaging, listening to, and addressing the concerns of all stakeholders in the global debate. One of the first things we must do is acknowledge concerns about unknown risks. History has shown that new technologies are not without risk. But history also has taught us that the benefits of a new technology can be much greater than the risks. And, the assessment of risks in the light of benefits ought to be the very essence of the current debate over biotechnology.

To meet future needs for safe and plentiful food, we at DuPont plan to improve our ability to provide crop protection products that fight plant disease and insect attack and that selectively control weeds with lower and more specific doses. We also will offer many of these same and improved benefits through seeds created with modern genetics. We know that the use of organic farming has grown and that we must understand how we can contribute to and learn from this part of the market. And, we plan to look for alliances and partnerships where we can make meaningful contributions to countries and regions of the world where food scarcity is a daily occurrence.

At DuPont, we believe so strongly in the importance of this issue that we have committed to four basic steps. First, we will engage, listen, and adjust. We will create a global biotechnology advisory panel to guide our actions; help us create positions on important issues; and guide and challenge us in the development, testing, and commercialization of new products based on biotechnology. We also ask this panel to audit our progress and provide a public report on a regular basis. Second, we will advocate informed consumer choice through meaningful information and product assurances. More and better science-based information must be made available to help with these choices. Third, we will take important steps toward the use of renewable resources and energy. We have set a goal of sourcing 10% of our energy needs in the year 2010 from renewable resources and deriving 25% of our revenues from areas other than those requiring depletable raw materials. Fourth, we will make the same commitment to the safe practice of biotechnology that we have made historically to industrial safety.

Role of Strategic Alliances

As we enter the new millennium, we know that no single agriculture company is going to succeed on its own. The future is about "systems." To win in a complex global arena, we must share our strengths with complementary partners and leverage our mutual capabilities to best serve customers and gain competitive advantage. These collaborations only work if there is real value for the customer and if the system is more effective than previously.

Our increasing concern for the environment – the recognition that the "how" of food production can have significant consequences for soil, water, and air quality, as well as for wetlands and forests – is now top of mind in many consumer-buying decisions. These shifts reflect the wide distribution of accumulated research findings over the past 25 years and our own increasingly sophisticated understanding of the linkages between food, health, safety, and the environment. We must incorporate this awareness into research decisions and investment dollars.

With this dynamic environment, it will be critical for cooperation, alliances, and partnerships between all the players – companies, governments, consumers, and producers. We must work together to achieve our joint agricultural vision. The global business environment must reflect the existence of a reasonable regulatory framework, fair and open competition, and the unfettered operation of market forces, as well as adequate intellectual property protection to justify the intensive investment in research and development.

Industry consolidation will continue, with economies of scale being the principal driver. Research and development and launching new products are expensive. The cost of bringing new products to the marketplace is further increased by ever more challenging societal demands leading to more stringent government regulations, such as the Food Quality Protection Act. There were 30 major crop protection players 10 years ago, with 15 accounting for approximately 85% of the business. Today, these numbers are about half and declining.

I also expect to see companies continue establishing positions and alliances along the value chain. Our Agriculture & Nutrition merger and acquisition activity began in 1997 when we acquired Protein Technologies and entered into a relationship with Pioneer Hi-Bred International, which became the newest member of the DuPont family on October 1. Together with Pioneer, we created Optimum Quality Grains, a value-added grains business, and we joined efforts in biotechnology research to speed enhanced crop developments to market and to consumers.

This is a very exciting time at DuPont. Combined with Pioneer, we have 11,000 employees, including 2,800 scientists, and have been investing $600 million on research and development every year. The merger will clearly increase our ability to deliver innovation to the marketplace.

Conclusion

In conclusion, biotechnology and information technology will provide major improvements in the crop protection industry's ability to help feed the world with higher-quality and more nutritious foods. Farmers will be able to grow customized crops that benefit people and businesses throughout the agricultural industry. Today, it is better corn and soybeans; tomorrow it will be better food, fibers, medicines, and even industrial products made from renewable resources. In its truest sense, this alliance offers better things for better living and will be a real demonstration of "The Miracles of Science™."

Within our industry, we have the resources and capability to provide leadership to agriculture. The mission must be to serve the customer and create value for them. Those who can remain on the cutting edge of technology and rapidly adapt to consumers' needs will prosper. In today's environment, the only constant is change. You have to be on your toes to deal with biotechnology, e-commerce, the knowledge explosion, and a myriad of potential new partnerships.

I appreciate the opportunity to share my thoughts on our industry's future. Today, we stand at the beginning of the new millennium. It certainly looks like an exciting journey ahead.

Agriculture and Crop Protection at the Onset of the New Millennium: The University's Role

STEVEN G. PUEPPKE

Now that we are literally on the cusp of the new century, it seems appropriate to look back at what we in the universities have accomplished in the area of crop protection – and then to link our past to some predictions about the upcoming decades. We would all agree that things are going to change for entomologists, plant pathologists, and weed scientists, but there would probably be a divergence of opinions on the exact nature of the future for pest control. Herein, I give my thoughts about these issues. But first we need to set the stage by thinking about where we are and how we got here.

Let's use the 1930s and 1940s as a baseline and consider the working environment for entomologists, plant pathologists, and weed scientists of 60–70 years ago. The following are some of the characteristics that come to mind, at least as they relate to land-grant institutions such as the University of Illinois.

- Research in the plant protection disciplines, for the most part, was applied and aimed at solving field problems. The work was done in greenhouses and fields more often than it is today – and the driving force was usually a problem that was reducing yields. Now we call these kinds of investigations "applied" or "problem solving" to distinguish them from more basic, laboratory-oriented discovery research.
- Plant protection, and indeed all agricultural sciences, were heavily discipline oriented. Growers looked to weed scientists to solve their weed problems, plant pathologists to take care of diseases, and entomologists to control insects. The university practitioners of these disciplines saw the world in the same way. Few would have viewed biochemists, plant physiologists, or geneticists as important assets for solving problems in the field.
- Research and information delivery were paid for by the states and the federal government, and so these institutions exerted heavy influence on the agenda.
- Research was linked fairly directly to a specially developed delivery system called Cooperative Extension. Often, the scientists who found the answers also did the delivering, and they usually were the only sources to which growers could turn for advice. Many of these individuals had farm backgrounds and shared a common, basic understanding of agriculture and its significance.
- Contact between extension agents and clientele was fairly extensive. County meetings, training schools, and short courses were offered routinely, and farmers turned to weekly newspapers and other printed materials for advice.
- Growers were relatively unsophisticated by today's standards. I have witnessed many changes in agriculture by watching my grandfather, my father, and now my two brothers farm in the Red River Valley of eastern North Dakota, and I have personally experienced these changes in terms of educational levels, understanding of the structure of agriculture, anticipation of future trends, and awareness of the global nature of the food system.
- Land-grant universities were viewed as the impartial source of objective information for farmers. This process was deliberate, not accidental.

Today's plant protection world is much different. Consider the following:

- Research portfolios at land-grant universities are usually balanced between discovery (i.e., generating a pool of fundamental knowledge) and application (i.e., solving problems of concern to growers). Few of us would dispute the contention that some discovery research has become disconnected from real-life problems. But we have to remember, too, that basic research has delivered. EPSP synthase was discovered not because it showed promise as a means to protect plants from the herbicide Roundup, but because it was part of basic biochemical investigations. The same is true for *Bacillus thuringiensis*, the source of many genes now used for transgenic control of insects.
- We now realize that pest control problems are complex, multidisciplinary, and best addressed by teams of researchers. Insects spread disease-causing bacteria and viruses; new cultivation practices are exacerbating and sometimes reducing pest problems; and control practices are increasingly based on biotechnological strategies. No one individual or discipline has all the answers.
- Research – and information delivery – are being underwritten not only by state and federal governments but also by a variety of external sources. Very few of today's researchers can maintain their programs on university funds, and universities let them know when they hire them that external support is expected. Faculty must turn to granting agencies and to the private sector for support, and this, of course, tends to skew the agenda.
- Linkages between research and extension are more tenuous than in the past. Many faculty positions that were once defined by a commodity (e.g., corn or soybean) are now defined by a discipline (e.g., bacteriology or physiology). Other positions have simply disappeared because land-grant universities have downsized and reoriented.
- There is less personal contact between the deliverers and those receiving information. This distancing is partly due to more work and fewer people, but technology also has intervened. We need to recognize that universities are no longer the exclusive purveyors of information – various segments of the private sector have become very active in information delivery, seizing the "market share" from public institutions.

So what does the future hold for the plant protection disciplines? I predict that we will see four main trends in the next 20 years.

1. There will be less need for the traditional disciplines and more need for interdisciplinary teams of problem solvers. Simultaneously, crop protection specialists will be trained more broadly so that they can better fit into research and information delivery teams.
2. Distinctions between discovery and applied research will blur. The research stream that leads to application will be initiated much further back in the discovery phase as we identify and exploit genes, for example, that are activated when plants are challenged by pests.
3. Ownership of data, almost a nonissue just a few years ago, will become crucial. More and more data will be generated privately and remain proprietary, and the proportional role of the land-grant university in plant protection research will decline, as life science companies invest heavily.
4. Producers will become much more sophisticated managers, and they will be bombarded with many options for pest control. Data availability and acquisition will not be the prime issue. Instead, producers will face new challenges in managing and using information.

Knowledge Creation and Tomorrow's Agriculture

STEVE SONKA

Illinois agriculture is faced with a myriad of challenges, not the least of which are price levels that strain profitability and decrease hard-earned net worth (minus government payment effects). Thus, it is difficult to focus on long-term issues but, at such times, it is critically important not to lose sight of long-term perspectives. The information presented herein draws heavily from "Information Technology and the Soybean Sector," *Revista agrosoft*. Agrosoft Fudacao Centro Technogicao. Juiz de For a, Brazil, No. 7. 1999.

In this article, I present one scenario of the future of crop production in Illinois. This scenario is not a prediction. The purpose of any scenario is to allow the decisionmaker to focus on what he or she would like to do today, if that scenario were to occur. In this way, the scenario frees us from the uncertainty of having to predict the future. The scenario described herein is one that I find intriguing for two reasons. First, through the use of information technology, it describes a type of agricultural decision making that is considerably different than that of our history or our current setting. Second, even though different for those of us in production agriculture, this scenario follows economic and managerial patterns that have emerged in every industry in which information technologies have redefined decision making.

In the following text, I provide a brief presentation of the scenario "Agriculture as a Knowledge Creating System" and outline conceptual foundations that explain the economic forces that would lead to such a scenario.

One Scenario of Agriculture's Future

Figure 1 describes the food and agricultural system in terms of three knowledge bases that could be sources of new value in tomorrow's sector. As sources of value, they have the potential to earn profits or excess economic rents. The traditional assets of land, labor, and capital will continue to earn returns but they will be minimal (what economists refer to as zero profits).

One knowledge base refers to biotechnology and the use of genetics to create value. A consumer and customer knowledge base is depicted (bottom, Figure 1) to reflect the value that can be earned by identifying and responding, with ever increasing precision, to consumer and customer demands in the marketplace.

The middle part of Figure 1 refers to a production agriculture knowledge base. This knowledge base would be augmented each time a crop or livestock

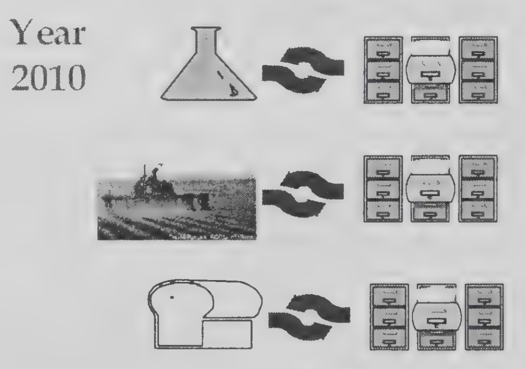


Figure 1 • Three knowledge bases as sources of "new" value.

Tomorrow's knowledge-creating system for production agriculture would

- Estimate the effect of alternative farm decisions on customer value
- Document the agronomic and economic results of ongoing farm operations
- Provide verification of environmental and food safety responsibilities
- Be linked to the research capabilities that will determine operations and customer value in the future

Figure 2 • Knowledge-creating system for production agriculture.

production cycle occurs. However, a truly effective ag production knowledge base must be much more than just a huge data file compiled from the operations of precision agriculture: it must integrate research from the laboratory and from field trials with data from actual farm operations. Thereby, the knowledge base is enhanced and continually creates new value.

Figure 2 presents four desired characteristics of a knowledge-creating system for production agriculture. Although novel in the context of production agriculture, these characteristics would be typical of a nonfarm, manufacturing-based system. Of key interest is the fourth characteristic, the link between research and actual operations.

Conceptual Foundations

Historically, control of assets was an important means by which individual farmers and large agribusiness firms achieved success. Decisionmakers, therefore, learned to become proficient with tactics to acquire and exploit the traditional assets of land, labor, and capital. Today, a fourth type of asset, knowledge, is increasingly being recognized as a critically important source of value.

Knowledge is not a new asset for farming or for the sector as a whole. There are two types of knowledge: explicit and tacit. Explicit knowledge is formal, repeatable knowledge that can be written down. Tacit knowledge refers to the informal experience-based insights, or judgments and experiences that decisionmakers use. The roles of explicit and tacit knowledge are very different historically from what they will be in the future. Explicit knowledge was discovered and validated in detail in research laboratories and experimental plots. That explicit knowledge was then communicated to farmers. Farmers combined that explicit knowledge with experience, judgement, and insight to make decisions. Historically, the cost of capturing, communicating, and analyzing explicit data from field operations exceeded the benefits of conducting these activities. Therefore, explicit information about actual field operations was only rarely available.

The technologies of precision agriculture and electronic communications via the Internet offer the potential to make available explicit information about actual farming operations. Thus, agricultural production would become even more like the manufacturing component of nonfarm economic sectors. To anticipate the potential effects of these technologies, the following discussion examines how information technologies have affected other sectors. Key managerial implications are suggested.

Strategic Implications of Information Technology

Information technologies tend to come to agriculture after development and adoption in other industries; thus, we should be able to learn from experiences in other sectors. Extensive analyses of the role of information technology in redefining industries throughout the economy, not just in agriculture, have been conducted. The results of these analyses indicate that information technologies affect two key characteristics of transactions: separability and aggregation potential. Separability refers to the extent to which specific information attributes can be captured in association with each transaction, and aggregation potential refers to the extent to which the information attributes can be leveraged through aggregation to gain economic value beyond the purpose of the original transaction. When the use of technology materially changes the nature of these characteristics, the stage is set for industry redefinition.

Examples abound where information technology has increased the level of separability and allowed aggregation to create value. Historically, when we bought items at the grocery store, we exchanged cash for the goods and the only information attribute captured was the amount of money received. Today, through customer preference cards and very detailed information about each item purchased, numerous attributes are captured about each transaction and each customer. Analytic tools are used to aggregate patterns

and to discover knowledge that is not available when looking at individual transactions.

Examination of nonagricultural experiences provides a different way to think about agricultural production. For example, we now can think of the information created *during* the production process as valuable output, in addition to the physical product produced. Precision agriculture and the Internet are technologies that allow us to capture and aggregate this information. This perspective suggests we should expect that use of these technologies would contribute to redefinition of agriculture.

Managerial Implications

These results have significant implications for food and agribusiness managers. Three key implications are outlined below.

1) Aggregation of precision agricultural data can provide economic benefits in three ways:
   - Development of new agronomic paradigms to directly improve crop production,
   - Enhanced market coordination for farm output, and
   - Reduced cost inefficiencies between input suppliers and producers.

Much of the attention and interest in precision agriculture has been focused on agronomic paradigm shifts. However, this benefit is the most difficult to achieve and requires several years before improvements are realized. Conversely, market coordination and cost benefits can be achieved quickly and with little uncertainty. Although these latter sources of benefits are not the focus of attention in agriculture, accessing these types of benefits has led to significant structural change in other sectors.

2) Managing intangibles will become increasingly important. Doing so is likely to include the following actions:
   - Building information links and relationships across the value chain,
   - Enhancing information management capabilities,
   - Testing alternative production systems before the effectiveness of the systems is widely known, and
   - Monitoring economic and market developments across the value chain and in other sectors.

In general, managers in agriculture value tangible, not intangible, assets. Thus, many managers are likely to be blind-sided by changes that are linked to exploiting intangible assets.

3) Although biotechnology, precision agriculture, and electronic communications are each important in their own right, their most profound effects will arise from the *interaction* of these three driving forces.

Concluding Comments

Precision agriculture and electronic communications are two current examples of technologies with considerable promise. Examination of the strategic implications of similar technologies in other sectors provides intriguing insights into the potential effects of precision agriculture and electronic communications. Hopefully, such insights can allow managers to more effectively exploit the benefits and mitigate the adverse effects of these technologies.

"Who's Driving the Bus?" A Farmer's View of the Next Century

DOUGLAS WILSON

When asked to envision agriculture in the next century, I must address the future from two perspectives: "How will ag look in the next century?" and "How will my farm look in the next century?" My answer to the first question should dictate my answer to the second, right? More specifically, what will my crop protection tools and needs be in the next century? Will genetically modified organisms (GMOs) be king, will we still be using petroleum-based products, or will we be farming organically? So, to address these questions from a farmer's point of view, I wonder how will government policies, industrial changes, academia (via education and research), and finance and economics affect farmers?

Who's driving the bus? Right now, 10 out of 10 farmers would say, "It's not me." Whether it's government policies, environmental issues, agribusiness influences, or the Chicago Board of Trade, farmers do not feel like they're much more than pawns. Our role, some would say, is to ensure that we will continue to supply a cheap product produced with inputs costing as much as the market will bear. Given the current situation, the lack of clear government policy, industry philosophies that push profits before ethics – and, yes, in several ways farmer stupidity – we have too many farmers raising too much product too cheaply. But it didn't have to be this way, and it won't remain this way. In this article, I propose where we are and what should happen for farmers and agriculture in the next century.

Government Policies – "Throw the bums out!"

Since 1996 and the last farm program, the federal government has not made many meaningful steps toward making Freedom to Farm a success. Trade issues are number one on their "list." If we had been exposed to Fast Track, Sanctions Reform, Meaningful Trade Agreements, etc., we would not be experiencing the agricultural economic decay that we currently face. Do I feel bad about having the federal government bailing us out? Yes, because it is a sign that what could have been corrected 3 years ago has never seen the light of day. But also, no, because if Washington D.C. is going to continue to play politics with agriculture, then congress and the administration need to take responsibility.

What should farmers be doing? They should be more politically involved. In the 2000 election, agriculture votes are being considered the swing vote by both sides to control Congress and the White House. The Midwest and its ag vote are on the screen of most politicians. If plans hold and with greater "grassroots" involvement, we should have more meaningful input in the process. Agribusiness companies, simply by opening their checkbook to contribute to an election, cannot overwhelm an active voter base. If you doubt this statement, you have only to look at the current GMO situation.

Environmental Issues – "Carol Browner, go home!"

Who will win the White House? The answer to this question alone will strongly influence how environmental regulations develop in the next century. But politics aside, what do we face? I suggest that no matter what happens in the election, agriculture will be watched more closely and I will have to do more reporting and face tighter controls on what I can and cannot do regarding fertility and crop protection. GMOs will be a part of that choice, but not until we move past our current issues. How will farmers gain control? We will have to look at products much harder and ask questions such as, Can I justify the "cost-to-benefits" of this product? Does it meet my needs for weed and insect control? But highest on the list is, How much hassle will be involved if I use this "silver bullet."

Agribusiness – The villains farmers face

We are seeing a dramatic decrease in the use of Bt corn and, to a lesser degree, Roundup Ready soybeans. Why? Confusion about the products and continuing changes in what is or is not okay is disgusting from a producer's point of view. We risk not only additional cost for these products but also the reality of lost markets. We as farmers were not as involved as we should have been, but this situation will change. The Illinois Corn Growers Association and the National Corn Growers Association started with "Know What You Grow;" next was "Know Where To Go;" and now we have "Corn 2000: A Producer's Handbook to Seed Selection." The days of, "Trust me, we know what's best" are past. The acceptance of "new is better" has been washed away with the GMO issue. Farmers have the option of being able to plant, protect, deliver, and pick their products from the grocery shelves from one company. That should be a plus, but right now it doesn't seem like it.

Academia – "Wake me when the lecture is over."

Universities are faced with not being able to provide information fast enough on some issues, or they are sometimes too quickly discounted by industry. We need more information from universities, but it has to be relevant to what's currently happening. That's not an easy task when most projects take several years of forward planning to be of use. However, academia will have to focus if it is to continue to receive producer support. Farmers will expect more, will be more specific in their requests, and will be more vocal about how they interpret the academia's response.

Business Management and Finance – "Please, sir, may I have some more?"

Although not always the ones driving the bus, business and finance managers are supplying the "gas money" and definitely have a say with most producers. Many small-town banks face the same problems that farmers face due to mergers, the bigger banks squeezing rates, and regulations swinging to favor the larger banks. However, at least for now, farm accounts do not interest most larger banks, and that leaves a producer's ability to work one on one with his or her lender intact. Farmers and lenders must look beyond the gate in the next century to new crops, new ways of reaching customers, and new alliances within agriculture.

Farmers and the Future

The bottom line is that we farmers know we have not been driving the bus, and it's gotten us not only lost but also in trouble. Farmers in the next century will look to control more of their own destiny. We'll use our political clout more effectively. With the Internet and other communication tools, we will be able to work more closely with our end users. We will not be shy about asking why a price goes up or down, and we won't stop at our local chemical dealer's office; we'll be asking Bill Kirk and others. We need to receive more of the real value of what we produce, and we'll be less tolerant of those who will try to block our efforts. If I am to gain the real value of what I produce, I cannot be satisfied with a premium slightly above the Chicago Board of Trade price. I am not an owner of a stone quarry, I will not be a bulk supplier. If I am, I will be no better off in the next century than I am today.

Can all farmers accomplish this end? No. Will we all be in business in the future? No. Are those of us who are left 10 years from now going to have better control? Yes!

UFOs in Illinois Soybean Fields

LOYD WAX

Unidentified foliar observations (UFOs) in soybean fields continue to occur every year on a substantial acreage in Illinois and throughout the Corn Belt. These symptoms, which resemble responses from certain foliar-applied herbicides, vary widely by year and location, and with environmental conditions, but on average are found each year on substantial portions of the soybean acreage in the Corn Belt.

Most of the fields that we have observed or that have been described to us, as well as plant samples submitted for diagnosis, seem to exhibit symptoms typical of those caused by foliar-applied plant growth regulator herbicides that are widely used for weed management in corn. That is, the observed symptoms appear on newly developed leaves and include leaf cupping, strapping, puckering, and crinkling. Most of these symptoms typically appear within 2 to 4 weeks after a postemergence herbicide application. However, the problem is becoming increasingly complex because additional herbicide formulations are routinely used, other herbicides are used in soybeans that may produce similar symptoms, and an increasing variety of adjuvants is included with both corn and soybean herbicides that may contribute to enhanced soybean response. In addition, some soybean herbicide formulations and adjuvants serve as excellent materials to help in "cleaning out" plant growth regulator residues that may remain in application equipment from previous mixtures.

We can identify many of the reasons for occurrences of adverse soybean responses. However, in some instances we, as well as many others, cannot pinpoint the causal agent, especially in fields where there seems to be good evidence that contamination by a growth regulator herbicide can be ruled out. This uncertainty adds to the frustration of the grower and the dealer or applicator, and to our frustration in being unable to determine conclusively the cause of the problem. The following text briefly outlines the nature of adverse soybean responses and some possible causes and solutions to UFOs in soybeans.

Possible Causes and Effects of UFOs in Soybeans

The most obvious causes of these foliar observations involve the inadvertent exposure of the soybean to plant growth regulator herbicides that are routinely used for weed management in corn. Our research in the 1960s described the symptoms and quantified the effects on soybean growth and yield that could be observed from various types of growth regulator herbicides. Treatments consisted of a wide range of very low dosages of the phenoxy, benzoic, and picolinic acid herbicides that simulated particle and vapor drift. The data indicated that extremely low dosages of these herbicides could cause substantial malformations of newly developing soybean leaves. It was also evident that soybeans could withstand considerable leaf malformations with no reductions in yield. However, slightly higher dosages of these growth regulator herbicides caused substantial yield reductions and maturity delays. Additionally, the data demonstrated that soybean varieties differed in their responses to these growth regulator herbicides.

Several other researchers in the Corn Belt conducted similar studies in the 1970s and 1980s to further clarify soybean response. This research included work on the likelihood of particle drift versus vapor drift

with various growth regulator herbicide formulations, with the greatest emphasis on dicamba and its formulations. Dicamba was selected because it seemed to cause the greatest soybean response at dosages likely to be encountered from particle or vapor drift. These studies confirmed our findings from the 1960s. We repeated our work in the late 1980s with modern soybean varieties, and the results of this research were similar to those of our studies in the1960s.

Following extensive educational efforts by both the public and private sectors concerning herbicide applications and the potential for particle and vapor drift, instances of drift from adjacent fields still occurred, but the frequency of these problems declined substantially.

Soybean leaf malformations also have appeared in fields where drift from growth regulator herbicides has been ruled out. It seems that these soybean injury symptoms were in some way associated with the postemergence soybean herbicide applied to the field for weed control. In some cases, it is apparent that in spite of good efforts by the applicator, equipment was not properly cleaned to thoroughly remove all traces of plant growth regulator herbicides. This residue resulted in the soybean herbicide solutions being contaminated with traces of some growth regulator herbicide that had been previously applied to a cornfield. Examination of label instructions for cleaning application equipment following the use of dicamba indicates the difficulty and time involved in performing thorough cleaning procedures. We, as well as others, have observed first-hand the ability of certain spray additives used in conjunction with postemergence herbicides to extract residues from spray equipment. This "inadvertent cleaning" can result in delivery of small quantities of plant growth regulator herbicides with the intended herbicide solution to the soybean foliage.

Educational efforts by private and public sector personnel have attempted to make growers and applicators aware of the potential problems of residues in application equipment. These efforts outlined potential problems with adjuvants, restated the need to clean application equipment thoroughly, and initiated the idea of dedicated application systems to further reduce the potential for herbicide spray solution contamination. Substantial progress has been made in this effort and both public and private sectors should be commended for this effort.

It also should be noted that several postemergence soybean herbicides can cause soybean plant responses that are similar to symptoms of exposure to plant growth regulator herbicides. Some of these herbicides cause stunting, yellowing, desiccation, and leaf crinkling under certain environmental conditions. As with the plant growth regulator herbicides, this injury is usually temporary and does not typically impact yield adversely. However, when herbicide applications are being made very late in the season and under very hot and humid conditions, significant soybean injury can occur from which the plants may not fully recover. Thus, we are hesitant to recommend or suggest late-season postemergence soybean herbicide applications.

Other Possible Causes of Abnormal Foliar Symptoms

In spite of excellent efforts on the part of extension personnel, growers, dealers, and applicators, we still have a variety of foliar symptoms that are manifested each year. Often, these symptoms tend to be associated more with sprayer patterns than with drift, but conversely, in some instances, do not appear to be associated with any sprayer pattern or the presence of any plant growth regulator herbicide.

As a result of the exchange of ideas among the public and private sector, some possible alternative causes for these symptoms have been discussed and are being considered: 1) Are there physiological responses that occur in soybeans under certain adverse environmental conditions that upset the hormonal balance within the plant? 2) Are there responses that are induced by or result from an interaction with other classes of soybean herbicides? 3) Are there responses from interactions of certain postemergence soybean herbicides with various insects or diseases? and 4) Does the genetic makeup of modern soybeans, including the herbicide-resistant crops, result in these symptoms, especially if trace amounts of plant growth regulator herbicides are involved?

Future Research

We recognize that this problem of UFOs remains a valid concern to those involved in weed management and crop production in Illinois and adjacent states. Although we do not have definitive answers for some soybean symptoms that have been encountered, we propose to increase our educational efforts to reduce these problems caused by drift, sprayer contamina-

tion, and spray additive selection. In addition, we would like to determine what possible herbicide interactions and environmental conditions might cause these types of symptoms. There have been some reports that these symptoms occur in the absence of herbicides, but to date no one has been able to demonstrate this. More than likely, if these symptoms can occur without involvement of a plant growth regulator herbicide, then a combination of genetic differences, herbicides, and unusual environmental conditions is involved. We also would like to establish techniques to determine whether exogenous plant growth regulator herbicides are involved with plants that exhibit cupping, puckering, and crinkling symptoms. We expect to start research on these UFOs in the near future.

Balance: What Tilted the Scales in 1999?

CHRISTY L. SPRAGUE

The 1999 growing season marked the initial commercialization of a new soil-applied corn herbicide in Illinois and 16 other states. Balance (isoxaflutole) herbicide is manufactured and marketed by Rhône-Poulenc Ag Company and is part of a new family of herbicides known as the isoxazoles. The commercialization of this herbicide provides an additional alternative for early preplant and preemergence weed control in corn. Research has shown that Balance provides excellent control of several small-seeded annual broadleaf weed species, including common waterhemp. One of its greatest strengths is in controlling velvetleaf. It also has good activity on a number of annual grass weed species. However, as with other selective herbicides, Balance may not adequately control certain weed species, and the use of herbicide tank-mixtures may improve weed control and broaden the weed control spectrum.

In its initial year, Balance was applied to >4 million acres across the 17 states in which it was registered. After the corn in some of these acres began to emerge, university extension personnel in Illinois and several other states began receiving inquiries and plant samples concerning Balance injury. Although the 1999 growing season marked the initial year of Balance commercialization, many universities throughout the United States had evaluated this herbicide in research trials for several years. Very few reported injury as severe as that seen in some producers' fields in 1999. So what is different this year compared with previous years in Illinois, when little or no injury occurred? What are some of the factors that may have contributed to the increased incidence of Balance injury to corn? What can be done to reduce or prevent this crop injury from Balance in the future? The following text tries to help answer these questions and to provide a greater understanding on how this compound works.

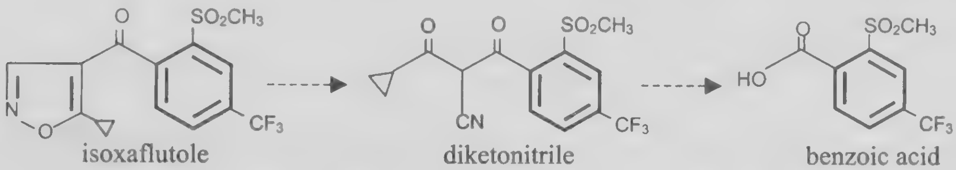
Mode of Action of Balance

Balance is a carotenoid biosynthesis inhibitor that causes bleaching or whitening symptoms in susceptible species, similar to that of other carotenoid inhibitors such as Command (clomazone). Carotenoids are accessory pigments that are essential for photosynthesis in plants. These pigments funnel additional light energy to the chlorophyll molecules and help dissipate excess energy when the chlorophyll molecules can no longer handle the additional energy. Balance indirectly inhibits the biosynthesis of carotenoid pigments by blocking the enzyme 4-hydroxyphenylpyruvate dioxygenase (HPPD) in the platoquinone pathway. Inhibition of this enzyme decreases levels of platoquinone, which is an essential cofactor of phytoene desaturase, an instrumental enzyme in the formation of carotenoids. If carotenoids are absent, chlorophyll molecules can no longer handle the excess energy, and damage to the plant membranes and chlorophyll molecules can occur. If these chlorophyll molecules are damaged extensively, injured plants lose their characteristic green color and appear white.

Metabolism of Balance

Balance selectivity to corn and other tolerant species is due to the ability of tolerant species to rapidly metabolize the phytotoxic form of the herbicide to nonphytotoxic compounds before extensive injury

occurs. It is important to understand this metabolic pathway to help explain the corn tolerance problems that producers faced during the 1999 growing season. Following foliar or root uptake, isoaxaflutole (Balance) is rapidly converted to a diketonitrile derivative by opening of the isoxazole ring. This diketonitrile derivative is the actual toxic form of this herbicide that inhibits HPPD, thereby blocking carotenoid biosynthesis. Diketonitrile is further degraded to a nonphytotoxic benzoic acid derivative. The extent and rate of this degradation step from diketonitrile to benzoic acid have been correlated to the degree of species tolerance and susceptibility.



Where Did Balance Injury Occur?

Environmental and Soil Conditions

In Illinois, there did not seem to be specific regions where more notable concerns from Balance injury occurred. Mostly, the injury seemed to be patchy, and observations indicated that the most notable injury occurred in areas where applications may have been doubled, such as along headland rows. Injury also may have been more severe in field areas where soils were low in organic matter and coarse in texture. Additionally, the cooler, wetter growing conditions early in the season may have increased the incidence of corn injury from Balance. As mentioned, the mechanism of Balance selectivity to corn is the ability of the corn plant to metabolize the active diketonitrile to the nonphytotoxic benzoic acid. The cooler weather and wetter soil conditions slowed overall plant growth and may have slowed the plant's ability to metabolize the herbicide.

These conditions are similar to those that occurred during the 1996 growing season in Michigan, where researchers reported significant corn injury from Balance. The cooler northern climate and the increased precipitation of that season resulted in corn injury from Balance applied at rates ranging from 1.5 to 3.0 oz/acre. The locations where this injury occurred had coarse soils with low organic matter. These factors may have increased the amount of herbicide in the soil solution, thus making more of the herbicide available for plant uptake. In these research trials, injury was more severe with higher rates of Balance, and in some cases severe injury resulted in corn yield reductions.

Hybrid Differences

Other instances of Balance injury during the 1999 growing season occurred in corn hybrid trials. In one of these trials, as many as 14 different corn hybrids were planted and treated with Balance, but only a few of these hybrids showed signs of herbicide damage. This observation suggests there are probably differences in corn hybrid tolerance to Balance. This observation is supported by previous research conducted to examine corn hybrid sensitivity to Balance. In these studies, differences in corn tolerance were quantified by determining the herbicide rate required to injure corn and reduce plant height. Of four different hybrids evaluated, two were less tolerant to Balance. Differences in hybrid tolerance were determined to be due primarily to differential herbicide metabolism rates of the active diketonitrile to the inactive benzoic acid.

Early Postemergence Applications

Other instances where Balance injury may have occurred in 1999 may be attributed to equipment failures and excessive rainfall, which delayed applications. Some of these delays may have resulted in applications being made after corn began to emerge. Previous research has shown that Balance applied to corn foliage increases the instances of injury, especially when tank-mixed with herbicides such as Dual II, Surpass, and Harness. It is important to follow the label and not apply this compound to corn after it has emerged.

Other Factors

Other factors that may have contributed to corn injury from Balance in 1999 include poor drainage, shallow planting, and failure to close the seed slot. All of these factors allow the herbicide to come into contact with the seed, which can result in increased incidences of injury.

These explanations may provide some answers to the widespread corn injury that occurred during the 1999 growing season. However, there were other cases where these factors do not appear to be the cause of Balance injury. So what happens in 2000? We do not have any clear answers; however, if extraordinary

environmental conditions explain the majority of Balance injury complaints in 1999, these conditions cannot be controlled from year to year. We do know that there are certain precautions that need to be taken when using Balance because it has a narrow corn safety margin. First, producers need to be aware that some corn hybrids vary in their tolerance to Balance. Second, it is important to follow the label and use the recommended rate specified for a specific soil type. Third, make sure that corn is planted at least 1.5 in. in depth and that the seed slot is closed. Finally, do not treat emerged corn with Balance.

Biology of and Methods for Controlling Palmer Amaranth

MICHAEL J. HORAK

Palmer amaranth, *Amaranthus palmeri*, is an annual weed native to the Sonoran Desert of North America. Prior to 1955, this species was found from southern California east to central Texas, and from the Oklahoma border south to central Mexico. Over the next 4 decades, the species spread to become a primary weed in the southeastern United States and throughout the southern Great Plains into Oklahoma, Kansas, southern Nebraska, and Missouri.

Palmer amaranth has numerous characteristics that enable it to be a successful weed. Palmer amaranth seed germinates more rapidly and seedlings grow more quickly than those of common waterhemp, redroot pigweed, and tumble pigweed. Palmer amaranth is capable of producing 900,000 and 400,000 seeds per plant when grown in noncompetitive situations and in competition with irrigated corn, respectively. It is an aggressive weed able to reduce irrigated corn yields from 20 to 90% at densities of 0.5 to 8 plants per meter of crop row. In soybeans, Palmer amaranth reduced yields 5 to 60% at densities of 0.25 to 8 plants per meter of crop row. Palmer amaranth also exhibits allelopathy; residues inhibit cabbage and carrot seedling growth up to 11 weeks after incorporation. Leaves of this species have the ability to change orientation to follow the solar track and are able to undergo osmotic adjustment to maintain high photosynthetic rates.

Palmer amaranth has separate male and female plants. It can hybridize with other pigweed species, which may be a means of acquiring advantageous traits. Palmer amaranth susceptibility to some postemergence soybean herbicides is less than that of redroot pigweed, common waterhemp, and tumble pigweed, and herbicide resistance to herbicides in the acetolactate synthase (ALS)-inhibiting triazine and dinitroaniline families has been documented. These characteristics, in part, explain the dramatic increase in the occurrence of Palmer amaranth.

In Illinois, Palmer amaranth has been found in scattered locations. It is likely that the species will increase in prevalence and severity as the species spreads or is inadvertently introduced to new areas. Palmer amaranth can be managed with timely practices and intensive control of new populations. Herbicides that are used to control other pigweed species are effective on nonherbicide-resistant populations; however, postemergence herbicide rates may need to be adjusted to achieve acceptable control.

Duration of Weed Competition in Roundup Ready Crops

DANIEL C. PARKER, F. WILLIAM SIMMONS, AND LOYD M. WAX

The advent of transgenic crops that allow for the use of nonselective herbicides with no soil residual has led to renewed interest in herbicide application timing and its effects on the duration of weed competition. Previously, application timing of herbicides was based on crop tolerance or weed susceptibility. However, transgenic crops have expanded weed control strategies by eliminating crop tolerance as a factor in herbicide application timing. Roundup Ultra is a nonselective herbicide that can control a large spectrum of weeds at larger growth stages than many other herbicides, thereby providing a wider window of application. Consequently, the timing of herbicide application can focus on eliminating weed competition during the important stages of crop growth. Application timing of Roundup Ultra is also important because it has no soil residual, so weeds can emerge later in the season to compete with the crop and possibly decrease yield.

Weeds compete with crops for light, water, nutrients, and space. The optimal application timing of Roundup Ultra is before weed competition becomes detrimental to the crop and just prior to canopy closure so the canopy can hasten the development of a second flush of weeds by shading the soil. Optimal application timing seems to vary with environmental conditions, weed species and pressure, and fertility.

The objectives of this study were to determine when weed competition becomes detrimental to corn and soybean development and yield and to determine the optimal application timing of Roundup Ultra for maximum yield of these crops without a soil-applied herbicide.

Corn

Field studies were conducted in Urbana, Illinois, in 1998 and 1999 to determine the optimal timing of glyphosate application in corn. Weeds were removed when they reached 2, 4, 6, 9, 16, or 20 in. in height. In two separate treatments, weeds were removed when they reached 2 or 4 in. in height; reinfesting weeds were controlled. A soil-applied herbicide for grass and broadleaf control also was evaluated.

The amount of sunlight intercepted by a corn plant influences its development and can be used to predict yield reductions. Thus, we evaluated the percentage of sunlight that corn intercepted for 3 weeks, beginning at the end of June. We found that the percentage of sunlight intercepted decreased with longer durations of weed competition. Most interception was possible when weeds were removed at ≤6 in. in height. Application of a preemergence herbicide also facilitated maximum light interception by corn. Controlling weeds at a 2- or 4-in. height required a second application to facilitate maximum light interception. Reduction in light interception was more pronounced in 1998 than in 1999. Reinfestation did not occur to a large extent in 1999 due to the corn canopy intercepting more light for all treatments. Allowing weeds to reinfest after being controlled at a 2-in. height decreased the ability of corn to intercept sunlight significantly in 1998. Allowing weeds to compete until they reached 9 in. in height resulted in a 20 to 30% reduction in light interception. This reduction was approximately 10% in 1999. This percentage is similar to that due to corn chlorosis and to height reduction caused by weed competition.

The yield reduction caused by weed competition was more severe in 1998 than in 1999. Corn in all treatments intercepted approximately 10 to 15% more sunlight in 1999 compared with 1998, which may be due to a higher growth rate early in the season. This could explain why weed competition was less severe in 1999. In 1998, yield decreased with longer weed durations, beginning with the timing of herbicide application when weeds were 6-in., for which yield was decreased by 13%. This reduction reached approximately 30% for the late timings and in treatments in which weeds were removed at 2 in. and weeds were allowed to reinfest. The preemergence herbicide effectively controlled all weeds through canopy closure and sustained maximum yield, thus demonstrating the deleterious effects of early-season weed competition and reinfesting weed competition. Applying Roundup Ultra to 4-in. weeds was the appropriate timing in 1998 because weed competition did not affect the crop, and weeds did not substantially reinfest. However, reinfestation may vary from year to year, and weeds may need to be controlled from the 4- to 6-in. height through canopy closure to preserve maximum corn yield. Allowing weeds to compete until 6 in. in height resulted in an 8% yield reduction in 1999. Reinfestation did not occur to a large extent in 1999, and there was no advantage to a second herbicide application.

Soybeans

Weed competition studies in soybeans were established at Urbana, Kilbourne, and Brownstown, Illinois, in 1998 and 1999. Weeds were removed at 2, 4, 6, 10, 12, and 20 in. in height. Separate treatments also controlled reinfesting weeds after the early timings.

Soybeans seem to overcome weed competition better than corn. Soybean canopy and height were not affected by weed competition in Urbana in 1998. Yields also were not affected to a large extent up to the timing of herbicide application when weeds were 12 in. in height. However, weed competition was more severe under the more stressful growing conditions and later planting dates at the other locations. Weeds competing until they reached 6 in. in height reduced the yield of soybeans at all locations. Soybean height and canopy closure also were reduced by this early-season weed competition. Canopy closure was more significantly affected, which may allow more weeds to reinfest. However, weeds emerging midseason did not reduce yield to the same extent as early-emerging weeds. We conclude that yield can be reduced by the time infesting weeds reach 6 in. in height, and that weed competition is more severe when water is a limiting factor.

Summary

Our research suggests that the duration of weed competition and the influence of reinfesting weeds are more severe in corn than in soybeans. Precise timing of Roundup Ultra application is needed to avoid inhibition of crop growth and to preserve maximum yield. These studies indicate that weeds should be removed by the time they reach 4 to 6 in. in height in corn, and 6 to 8 in. in height in soybeans to preserve maximum yield. Weeds also need to be controlled through canopy closure, which seems to be more important in corn than soybeans.

Burndown Application Timings in Roundup Ready Soybean

ANDREW KNEPP, LOYD WAX, AND BRYAN YOUNG

Difficulties and increased costs of weed control in no-tillage soybean production have been a deterrent for the adoption of no-tillage production practices. Traditional weed control strategies in no-tillage soybean production systems consist of nonselective "burndown" herbicide treatments or a preemergence (PRE) treatment of a residual herbicide that has some foliar activity to control existing vegetation. These treatments are typically followed by one or two selective postemergence (POST) herbicide treatments in season to achieve adequate control of all weeds present in the field. The commercialization of Roundup Ready soybean has the potential to drastically change traditional weed control practices in no-tillage soybean for some growers in Illinois.

Roundup has been used extensively as a nonselective burndown treatment to control existing vegetation in no-tillage soybean production systems. Due to its nonselective nature, applications of Roundup were normally made only prior to crop emergence. However, with Roundup Ready soybean varieties, applications of Roundup are no longer limited to burndown in no-tillage soybean. Because Roundup can control existing vegetation without danger of crop injury, the traditional burndown application may be unnecessary.

Exclusion of burndown treatments from no-tillage production systems would significantly reduce herbicide inputs and also allow growers greater flexibility in herbicide application timings. Many burndown treatments include the use of 2,4-D. Although inexpensive, 2,4-D prevents growers from planting soybean for up to 10 days because of risk of crop injury. Significant rainfall during this period also may cause the grower greater delays in planting. Eliminating this type of burndown treatment allows growers the option to plant when conditions are suitable and without concern for crop injury. The overall effectiveness of reducing or eliminating burndown treatments, however, is dependent on the weed spectrum of the field, POST application timing, and efficacy of in-season weed control.

Numerous studies have proven the benefits to weed control with narrow row spacing (<30 in.) versus wide row spacing (30–40 in.) in both conventional and no-tillage soybean production. By decreasing the number of days to full canopy, narrowed rows can more effectively compete for light and other resources with existing weeds while reducing or eliminating the subsequent germination of other weed species. One common way to achieve narrow row spacing is by using a grain drill (typically 7–8-in. row spacing) to plant the seeds.

Interest in and availability of planters with 15-in. row spacing has greatly increased the number of acres planted with such machinery. There is a consensus among many growers that these planters offer several agronomic benefits over drills. These benefits include, but are not limited to, better seed placement, better population control, and more uniform early-season stands. Although it was beyond the capabilities of this study to compare the agronomic properties of each type of planting equipment, this study was intended to investigate whether there are differences in weed control and yield between the row spacing of the two systems.

Weed Control Strategies

Field studies were conducted in 1997, 1998, and 1999 at DeKalb, Urbana, and Belleville, Illinois. Weed control strategies were placed into three categories: 1) full burndown, 2) reduced or low burndown, and 3) no burndown. The full burndown treatment was Roundup at 1.5 pt/acre and 2,4-D at 1 pt/acre applied early preplant (EPP, 7–10 days before planting). The reduced or low burndown treatment was Canopy at 2.0 oz/acre and 2,4-D at 1 pt/acre EPP. The full and low burndown treatments were both followed in season by either a single application of Roundup at 1 qt/acre POST or a sequential treatment (POST followed by late postemergence [LPOST]) of Roundup at 1.5 pt/acre. Treatments receiving no burndown were Roundup at 1 qt/acre applied at planting (PRE), at the early postemergence (EPOST) timing (3–4 weeks after planting), or at the postemergence (POST) timing (4–6 weeks after planting). Roundup applied PRE was followed by an in-season application of Roundup at 1qt/acre POST.

Summary

No crop injury was observed 60 days after planting. However, burndown applications including Canopy did cause a small amount of transient soybean injury observed after soybean emergence. All burndown treatments were effective at controlling most of the emerged weeds. At all locations, control of giant foxtail with Canopy was lower compared with Roundup. Despite this decreased control, POST applications of Roundup effectively controlled giant foxtail in those treatments.

Weed control with POST applications of Roundup was extremely consistent. Control ratings 60 days after planting indicated >90% control of most summer annual weeds (giant foxtail, common lambsquarters, velvetleaf, giant ragweed, and horseweed). Although weed pressure was high, there was no difficulty controlling perennial weeds or any weed species that were not easily controlled by Roundup. Presence of these types of weeds in a grower's field may decrease the overall effectiveness of any Roundup Ready system.

Response of soybeans to these particular weed control strategies varied by location. At DeKalb, weed control could be delayed until the POST timing with no reduction in yield compared with the weed-free check. However, waiting until the POST timing did cause significant yield reduction at Urbana. Exclusion of a burndown treatment at Belleville posed a greater risk than at the other two locations. Delaying application until EPOST caused yield reduction at Belleville. The cause of these yield reductions is most likely early-season competition. The earlier warm weather of Belleville and Urbana allows for early germination and more vigorous growth of the weeds. Therefore, the weeds are larger and have a greater competitive advantage over the soybeans. At all locations, the application of Roundup PRE followed by an in-season application(s) of Roundup gave excellent weed control and produced yields similar to the weed-free check. This PRE program still offers growers flexibility to plant when conditions are optimal without fear of crop injury from EPP herbicide applications.

Sequential in-season applications (POST followed by LPOST) of Roundup failed to provide increased weed control or increased yield. However, sequential applications of Roundup may be warranted with a spectrum of late-season germinating weeds such as waterhemp, nightshade, or morningglory species.

There was no clear benefit of 15-in. rows over drilled soybeans. Little difference in weed control existed between the two systems, suggesting that 15-in. rows may offer the same advantage in weed control as drilled soybeans when compared with 30-in. rows. At Belleville and Urbana, yield reduction occurred slightly more often in the 15-in. rows, indicating that drilled soybeans may still offer a competitive advantage if weed control is delayed.

Weed Management in Roundup Ready Soybeans: Is Roundup the Only System?

BRYAN YOUNG

Years of experience with Roundup have demonstrated effective control of a broad spectrum of broadleaf and grass weeds. However, because Roundup has no soil residual activity, weeds emerging after the herbicide application will not be controlled. Producers may postpone the application of Roundup to reduce the amount of weeds emerging after application but the increased weed size at a late postemergence (LPOST) timing may reduce the control of certain weeds. Control of velvetleaf (*Abutilon theophrasti* Medik.), ivyleaf morningglory [*Ipomoea hederacea* (L.) Jacq.], Pennsylvania smartweed (*Polygonum pensylvanicum* L.), and common lambsquarters (*Chenopodium album* L.) was decreased when Roundup application was delayed (Krausz et al. 1996, Wait et al. 1996, Franzenburg et al. 1998). Furthermore, delaying the Roundup application may increase the risk of soybean yield loss due to weed competition. Several studies reported reductions in soybean yield when the Roundup application was delayed to an LPOST timing (Vidrine et al. 1996, Dobbels and Loux 1997, Evers and Smeda 1998).

Sequential applications of Roundup may increase overall weed control and reduce the risk of yield reduction due to weed competition. Previous research showed that sequential applications of Roundup provided greater overall weed control compared with single applications (Claassen et al. 1997, Palmer et al. 1997, Smith et al. 1997). Soybean yield was greater with sequential Roundup applications compared with a single Roundup application (Oliver et al. 1996, Claassen et al. 1997, Marshall et al. 1998).

Planting soybeans in narrow rows also can enhance weed control for a given herbicide treatment because of rapid closure of the soybean canopy (Burnside and Colville 1964, Peters

Table 1 • Common waterhemp control averaged across years at Belleville and Urbana, Illinois.

			Bellevillle			Urbana		
			Row spacing (in.)					
Treatment	Rate	Timing	7	15	30	7	15	30
			% Control					
Roundup	1.0 pt/acre	POST	92	94	82	94	94	80
Roundup	1.5 pt/acre	POST	95	94	82	95	92	83
Roundup	2.0 pt/acre	POST	98	96	89	99	96	86
Roundup	1.0 pt/acre	LPOST	93	92	74	96	93	74
Roundup	1.5 pt/acre	LPOST	95	98	88	98	95	88
Roundup	2.0 pt/acre	LPOST	99	96	93	98	95	88
Roundup + Roundup	1.0 pt/acre + 1.0 pt/acre	POST + LPOST	99	96	93	98	95	90
Roundup + Roundup	1.5 pt/acre + 1.5 pt/acre	POST + LPOST	99	98	86	99	99	96
Prowl + Pursuit DG	2.4 pt/acre + 1.4 oz/acre	PRE + EPOST	75	72	59	80	85	79

EPOST, early postemergence; LPOST, late postemergence; POST, postemergence; PRE, preemergence.

Table 2 • Velvetleaf control averaged across years at Belleville, DeKalb, and Urbana, Illinois.

			Bellevillle			DeKalb			Urbana		
			Row spacing (in.)								
Treatment	Rate	Timing	7	15	30	7	15	30	7	15	30
			% Control								
Roundup	1.0 pt/acre	POST	82	74	72	82	76	79	95	97	87
Roundup	1.5 pt/acre	POST	85	83	74	90	81	80	95	96	87
Roundup	2.0 pt/acre	POST	88	85	83	89	84	84	98	97	91
Roundup	1.0 pt/acre	LPOST	85	78	82	88	90	83	90	96	79
Roundup	1.5 pt/acre	LPOST	90	90	83	92	86	84	95	94	87
Roundup	2.0 pt/acre	LPOST	86	91	79	89	87	88	96	96	90
Roundup + Roundup	1.0 pt/acre + 1.0 pt/acre	POST + LPOST	91	83	87	91	89	91	98	97	92
Roundup + Roundup	1.5 pt/acre + 1.5 pt/acre	POST + LPOST	93	90	88	93	93	91	98	97	92
Prowl + Pursuit DG	2.4 pt/acre + 1.4 oz/acre	PRE + EPOST	97	91	91	94	91	82	91	92	86

EPOST, early postemergence; LPOST, late postemergence; POST, postemergence; PRE, preemergence.

et al. 1965, Wax and Pendleton 1968, Legere and Shreiber 1989, Mickelson and Renner 1997). The shading provided by the canopy in narrow rows may eliminate the need to use sequential applications. Planting soybean in 15-in. rows as an alternative to 7- or 30-in. rows has gained in popularity among Illinois soybean producers. It is uncertain whether weed management in 15-in. rows will be similar to that in the narrow 7-in. row spacing or in the wider 30-in. row spacing.

The objectives of this research were to determine the effect of row spacing, Roundup rate, application timing, and number of applications on weed control and yield in Roundup Ready soybeans. In addition, research was conducted to evaluate weed management systems in conventional, Roundup Ready, sulfonylurea-tolerant soybeans (STS), and Liberty Link soybean varieties with typical herbicide treatments.

Weed Management in Roundup-Only Systems

Studies were conducted in 1996, 1997, and 1998 at Belleville, DeKalb, and Urbana, Illinois, to compare weed control with Roundup in 7-, 15-, and 30-in.-row soybeans. Single applications of Roundup at 1, 1.5, and 2 pt/acre were made when weeds were approximately 2 to 4 (POST) and 6 to 8 (LPOST) in. in height. Sequential applications of Roundup at either 1 or 1.5 pt/acre also were evaluated. Additional treatments in each study included Prowl (preemergence [PRE]) followed by Pursuit (early postemergence), a nontreated check, and a weed-free check. Visual weed control was evaluated approxi-

Table 3 • Range of velvetleaf control averaged across years at Belleville, DeKalb, and Urbana, Illinois.

Treatment	Rate	Timing	7-in. rows	15-in. rows	30-in. rows
			% Control		
Roundup	1.0 pt/acre	POST	72–99	68–99	67–99
Roundup	1.5 pt/acre	POST	83–99	78–99	68–99
Roundup	2.0 pt/acre	POST	82–99	80–99	72–96
Roundup	1.0 pt/acre	LPOST	75–99	70–99	48–87
Roundup	1.5 pt/acre	LPOST	83–99	80–99	70–99
Roundup	2.0 pt/acre	LPOST	77–99	78–99	77–99
Roundup + Roundup	1.0 pt/acre + 1.0 pt/acre	POST + LPOST	85–99	75–99	80–98
Roundup + Roundup	1.5 pt/acre + 1.5 pt/acre	POST + LPOST	90–99	88–99	85–98
Prowl + Pursuit DG	2.4 pt/acre + 1.4 oz/acre	PRE + EPOST	82–99	85–99	65–99

EPOST, early postemergence; LPOST, late postemergence; POST, postemergence; PRE, preemergence.

Table 4 • Soybean yield averaged across years at Belleville, DeKalb, and Urbana, Illinois.

			Bellevillle			DeKalb			Urbana		
			Row spacing (in.)								
Treatment	Rate	Timing	7	15	30	7	15	30	7	15	30
			Soybean yield (bu/acre)								
Roundup	1.0 pt/acre	POST	40	45	37	50	54	51	57	58	48
Roundup	1.5 pt/acre	POST	44	44	41	50	55	47	63	56	53
Roundup	2.0 pt/acre	POST	46	50	43	50	56	50	64	58	54
Roundup	1.0 pt/acre	LPOST	46	47	33	49	51	47	56	61	50
Roundup	1.5 pt/acre	LPOST	48	49	43	47	50	50	71	59	53
Roundup	2.0 pt/acre	LPOST	48	50	42	49	50	51	65	57	53
Roundup	1.0 pt/acre	POST	46	49	47	51	50	53	64	61	58
+ Roundup	+ 1.0 pt/acre	+ LPOST									
Roundup	1.5 pt/acre	POST	52	48	44	51	54	50	64	61	55
+ Roundup	+ 1.5 pt/acre	+ LPOST									
Prowl	2.4 pt/acre	PRE	42	37	38	44	47	50	60	57	47
+ Pursuit DG	+ 1.4 oz/acre	+ EPOST									
Nontreated			13	21	10	29	24	26	39	35	24
Weed free			50	51	49	49	55	50	63	63	57

EPOST, early postemergence; LPOST, late postemergence; POST, postemergence; PRE, preemergence.

mately 5 weeks after the POST application. Soybean yield was determined by harvesting the center of each plot and seed yield was corrected to 13% moisture.

In general, giant foxtail control was good with all Roundup treatments, regardless of Roundup rate or application timing. Roundup treatments usually provided giant foxtail control that was equal to or slightly greater than the standard treatment of Prowl followed by Pursuit. Roundup treatments provided greater common waterhemp control in 7- and 15-in. rows compared with 30-in. rows (Table 1). Common waterhemp control in 30-in. rows was increased when sequential applications of Roundup were used. Average common waterhemp control with the standard treatment of Prowl followed by Pursuit was 95% in 1996 but only 53% in 1998. The poor common waterhemp control observed in 1998 was probably due to the presence of waterhemp resistant to Pursuit at both Belleville and Urbana.

Velvetleaf tended to be more difficult to control with Roundup than giant foxtail or common waterhemp. In some studies, increasing the Roundup rate or using sequential applications of Roundup increased velvetleaf control; however, results were inconsistent across sites and years (Table 2). Table 3 reveals the variability in velvetleaf control with each Roundup treatment across sites and years.

All herbicide-treated plots yielded greater than nontreated plots; however, some herbicide-treated plots did not yield as high as the weed-free check (Table 4). The greatest yield reductions were usually observed with treatments that failed to adequately control common waterhemp at Belleville and Urbana.

Comparison of Conventional and Herbicide-Resistant Soybeans

A study was conducted at Belleville, Illinois, in 1999 to compare weed control in conventional (nonherbicide resistant), Roundup Ready, STS, and Liberty Link soybeans. Asgrow 4922, Asgrow 4602 RR, Asgrow 4604 STS, and Asgrow 5547 LL soybeans were planted on May 26. Herbicide treatments were selected based on the variety of soybean and the weed spectrum. Treatments applied to each soybean variety are listed in Table 5. Weed control was visually evaluated 56 days after planting.

All of the herbicide treatments used in the conventional and Roundup Ready system controlled at least 91% of giant foxtail and common waterhemp (Table 5). A single application of Liberty controlled only 69% of giant foxtail and 65% of common waterhemp in Liberty Link soybeans. However, applying Authority PRE prior to Liberty or using a sequential application of Liberty increased giant foxtail and common waterhemp control to at least 98%. In STS soybeans, giant foxtail control was at least 96% with treatments

Table 5 • Weed control 56 days after planting and cost of herbicide programs in conventional, Roundup Ready, Liberty Link, and STS soybeans.

	Rate	Timing[1]	Giant foxtail	Common waterhemp	Common ragweed	Penn. smartweed
			% control			
Conventional[2]						
Flexstar + Fusion	1.25 pt/acre +	POST	99	97	98	96
Authority +	8 oz/acre	PRE +	99	99	99	99
	4 oz/acre +					
Flexstar +	1.25 pt/acre	POST2				
Fusion	+ 8 oz/acre					
Prowl +	2.4 pt/acre +	PRE +	94	98	99	99
Flexstar	1.25 pt/acre	POST2				
Roundup Ready						
Roundup Ultra	2 pt/acre	POST	96	91	99	97
Authority +	4 oz/acre+	PRE +	99	99	99	99
Roundup Ultra	2 pt/acre	POST				
Roundup Ultra +	2 pt/acre	EPOST	99	99	99	99
Roundup Ultra	+ 2 pt/acre	+ POST3				
Liberty Link						
Liberty	24 oz/acre	POST	69	65	97	95
Authority +	4 oz/acre +	PRE +	98	99	98	99
Liberty	24 oz/acre	POST2				
Liberty +	24 oz/acre +	EPOST	99	99	99	99
Liberty	24 oz/acre	+ POST3				
STS						
Synchrony +	0.5 oz/acre +	POST	96	15	96	99
Assure II	10 oz/acre					
Authority +	4 oz/acre +	PRE +	97	95	98	99
Synchrony +	0.5 oz/acre +	POST2 +				
Assure II	10 oz/acre	POST2				
Prowl +	2.4 pt/acre +	PRE +	78	53	95	98
Synchrony	0.5 oz/acre	POST2				

[1] Application dates: preemergence (PRE), May 26; early postemergence (EPOST), June 18; postemergence (POST), June 25; postemergence following PRE (POST2), June 22; sequential postemergence (POST3), July 6.

[2] Flexstar treatments included Sun-it II at 1.0% v/v and 28% urea ammonium nitrate (UAN) at 2.5% v/v. Roundup Ultra and Liberty treatments included ammonium sulfate at 2.0% w/w. Synchrony treatments included crop oil concentrate at 1.0% v/v and UAN at 2.5% v/v.

that included Assure II, but only 78% with Prowl PRE followed by Synchrony. Only Authority PRE followed by Synchrony plus Assure II provided good control of common waterhemp in STS soybeans. All of the herbicide treatments controlled at least 95% of common ragweed and Pennsylvania smartweed.

Conclusions

Effective weed control can be achieved with Roundup Ultra, although the presence of difficult-to-control species such as waterhemp and velvetleaf may require adjustments in the Roundup Ultra rate, number of Roundup Ultra applications, or soybean row spacing. The level of weed control observed with Roundup Ultra in Roundup Ready soybeans was similar to the weed control observed with herbicide programs in conventional, Liberty Link, and STS soybeans. Because effective weed control can be achieved in herbicide-resistant and conventional soybeans, more emphasis should be placed on overall yield and profitability or on the herbicide–crop program.

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Weed Control in Soybeans with Valor

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Valor (flumioxazin) is a new herbicide being developed by Valent for broadleaf weed control in soybeans and peanuts. It provides control of several species of problematic weeds found in Illinois, including common lambsquarters, pigweed, waterhemp, kochia, common ragweed, black nightshade, and prickly sida. In addition, weeds such as giant ragweed, morningglory, and some grass species may be suppressed by Valor. The herbicide may be applied early preplant or preemergence at rates of 0.062 to 0.094 lb (AI)/acre. When used in combination with a burndown herbicide, Valor exhibits some nonselective foliar activity, in addition to providing 4–6 wk of residual weed control. The mode of action for Valor is inhibition of protoporphyrinogen oxidase, an enzyme necessary for the production of chlorophyll.

Environmental characteristics of Valor include favorable toxicology, low use rate, and rapid soil dissipation, reducing the potential of carryover or leaching problems. It also can be used as a tool for the management of weeds resistant to acetolactate synthase (ALS) inhibitors and triazine herbicides by introducing an alternative mode of action into the system. With the increasing use of postemergence herbicides in soybeans, Valor may provide the residual weed control important in reducing early weed competition.

Waterhemp Control with Valor

Common waterhemp is a weed that is becoming an increasing problem in Illinois as biotypes resistant to both ALS inhibitors and triazine herbicides develop and spread throughout the state. Because Valor and Authority offer a new mode of action, they were tested at a range of rates for activity on common waterhemp with trials in Urbana (conventional tillage) and in St. Elmo (reduced tillage). Early preplant applications were made approximately 2 weeks before planting with rates ranging from 0.094 to 0.125 lb (AI)/acre Valor or from 0.188 to 0.244 lb (AI)/acre Authority. Preemergence applications covered a greater range of rates, from 0.031 to 0.125 lb (AI)/acre Valor or from 0.094 to 0.244 lb (AI)/acre Authority.

In 1998, Valor controlled common waterhemp with 0.078 lb (AI)/acre at both locations, whereas Authority controlled this weed with 0.164 lb (AI)/acre in St. Elmo and 0.188 lb (AI)/acre in Urbana. Normal use rates of both herbicides controlled giant foxtail in St. Elmo but not in Urbana. The herbicides were not as effective in 1999 at the Champaign location because 0.109 lb (AI)/acre Valor was required to control common waterhemp. However, the early preplant (EPP) applications, which were applied only 5 days prior to planting, provided greater control than they had the previous year. Both herbicides provide a good alternative for common waterhemp control and rates may need to be adjusted based on soil type, tillage practice, and weed pressure.

Valor in a Program Approach

Because Valor offers residual weed control early in the season, it is likely to be used in a herbicide program that includes a postemergence application of a different herbicide. Trials were established in Urbana and DeKalb to compare Valor and Prowl applied

preemergence, followed by postemergence applications of Pursuit, Raptor, or Roundup Ultra. The preemergence herbicides were used alone at the full rates (0.094 lb [AI]/acre Valor or 1.00 lb [AI]/acre Prowl), or combinations at the 1X, ¾X, or ½X rates. All postemergence herbicides were used at the recommended rates with appropriate adjuvants.

In 1998, Valor controlled morningglory, common cocklebur, common lambsquarters, and Pennsylvania smartweed prior to the postemergence herbicide application. However, in 1999 Valor only provided control of common lambsquarters and pigweed before postemergence applications. After postemergence applications were made, Valor increased activity on morningglory, velvetleaf, and giant ragweed compared with all postemergence herbicides alone and on common lambsquarters and cocklebur compared with Pursuit or Raptor alone. Valor was superior to Prowl for control of most weed species and provided a good base for herbicides applied postemergence.

Soybean Injury Concerns

To determine the potential for soybean injury, Valor was compared with Authority because they exhibit the same mode of action. Several studies have demonstrated that Authority may cause soybean injury, and that cultivars vary in sensitivity (Oliver et al. 1997). Although detoxification in soybeans is metabolism based, cultivar variation appears to result from differential tolerance to the herbicide-induced peroxidative stress (Dayan et al. 1997). Swantek et al. (1998) showed that this phenomenon is controlled by a single gene and that tolerance is dominant. Although the sensitivity of some cultivars increases the likelihood of injury, environmental conditions also play a critical role. It has been demonstrated that low soil organic matter and high moisture increase Authority injury (Wehtje et al. 1997). The availability of the herbicide increases with higher pH and coarse soil texture, also affecting injury (Grey et al. 1997).

Greenhouse studies were established to compare the response of 15 soybean varieties to applications of Valor or Authority. The effect of herbicide rate on soybean injury from the two herbicides also was determined. An assessment of all varieties combined revealed that Valor caused negligible injury, whereas Authority applied at the normal use rate (0.2 lb [AI]/acre) caused an average of 10% injury. Valor at a 2X rate caused little difference in injury among all varieties, with each variety showing <10% injury. With a 2X rate of Authority, a wide range of injury responses occurred with four varieties demonstrating high injury (40–60%), four varieties demonstrating medium injury (10–20%), and the remaining seven varieties exhibiting little injury (<10%).

A field study was initiated to compare four of the soybean varieties for sensitivity to Authority and Valor to determine if the injury resulting from these herbicides would cause significant reductions in yield. The trial was conducted in 1998 and 1999 in Urbana, Illinois, on an Elburn silt loam with approximately 3.5% organic matter. The four soybean varieties included two that were tolerant to Authority and two that were sensitive, based on the greenhouse study. Three rates of each herbicide were applied from a 1X to 4X use rate to increase the chances for injury. In 1998, the environment between the time of planting and emergence of the soybeans was wet and conducive to injury. Based on stand counts, soybean varieties differed in their injury response to Authority and to a lesser extent, Valor. Early injury symptoms to soybeans were greater for Authority than for Valor, and injury consisted of delayed emergence, reduced stand counts, and necrosis on the cotyledons and unifoliolate leaves. In 1999, the environmental conditions after planting were more favorable, and injury was not as great as it had been in 1998. At normal use rates of Valor and Authority, injury caused by the herbicides did not cause a significant yield reduction.

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Balancing the Dual Axioms of Weed Control: Topnotch Approaches for Harnessing Grasses and Surpassing Control on the New Frontier

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The soil-applied acetamide market in corn is still a significant and competitive marketplace where performance profiles across application timings determine use and market share. In the past few years, two new herbicides have been introduced: Axiom by Bayer Corporation (flufenacet and metribuzin) and, most recently, Degree by Monsanto (formerly MON 58430, encapsulated acetochlor). Dual Magnum is the active isomer of metolachlor and allows for a lower use rate than the "old" Dual. BASF also has purified an active isomer of dimethenamid (Frontier) that allows its use rate to be lowered while maintaining the same efficacy. These herbicides are the most recent ones on the market. Future changes in the use patterns of these herbicides may occur in transgenic corn, in mixes with isoxaflutole and similar herbicides, and in formulations that allow postemergence application of these herbicides.

Persistence is an important property of soil-applied herbicides and of some postemergence herbicides because it allows for extended weed control. When the herbicide remains unaltered in the soil during the crop season of application, it is an advantage. If a herbicide remains in the soil and is present when a rotational (and susceptible) crop is planted, the persistence causes herbicide carryover. Most herbicides do not carry over. Degradation rates in the soil under normal environmental conditions typically reduce herbicide concentrations to sublethal levels for rotational crops. Some herbicides provide additional safety because they are not injurious to rotational crops.

Shifts in herbicide application timing to earlier applications have put a premium on herbicide persistence to coincide with weed emergence. The resistance to degradation and downward movement within the soil profile are both important to obtaining satisfactory weed control.

Persistence is an important characteristic of a herbicide because it affects efficacy, exposure to environmentally important transport, and carryover to subsequent crops. Persistence is the integrated result of all herbicide-loss pathways that act upon the parent compound when it is in the soil environment.

Degradation of many herbicides follows first-order kinetics, meaning that the rate of degradation is roughly proportional to the herbicide concentration. The half-life, or time when 50% of the parent compound is gone, is a herbicide property that is frequently cited in technical information and promotional literature. Under field conditions, the half-life is variable and dependent upon environmental conditions.

Factors Affecting Persistence

The main herbicide-loss pathways in soil are microbial breakdown and chemical breakdown, both of which are primarily driven by reactions with water. Herbicide degradation mechanisms that involve microorganisms operate best at optimum soil temperature and moisture for growth of microorganisms. Nonbiological chemical reactions also are typically enhanced with increased temperature. Water is essential for microbial activity and increases aerobic processes until saturation occurs and gas transfer with the atmosphere is hampered. Soil texture and organic matter content have a surprisingly small effect on carryover because the differences in water and nutri-

ent availability are often counterbalanced by the difference in herbicide adsorption. Thus, a fertile soil, rich in organic matter, may promote faster herbicide degradation but also have less herbicide available to degrade because of its greater number of adsorption sites.

Soil pH is important in affecting the stability of some herbicides and herbicide families. High soil pH associated with calcitic soils, overliming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover. This carryover may be important for triazines and some sulfonylureas. Hydrolysis, an important breakdown mechanism, slows significantly at soil pH values near 7.0.

Results from Field Studies

Field studies were conducted in 1998 and 1999 at three locations in Illinois – DeKalb, Annawan, and Dwight. Soil samples from the sprayed plots were used in laboratory studies to examine herbicide persistence in a demanding greenhouse environment. The chloroacetamide herbicides evaluated included metolachlor (Dual), the active isomer of metolachlor (Dual Magnum), flufenacet and metribuzin (Axiom), acetochlor (Surpass or Harness), and two capsule suspensions of acetochlor (Topnotch and Degree). Five application timings – fall, 60-day early preplant (EPP), 30-day EPP, preplant incorporated (PPI), and preemergence (PRE) – were tested at all three locations. The study was carried out in fields of corn following soybean. Prior to planting, all fields received shallow field cultivation. The PRE treatments were applied directly after planting.

Axiom, Dual formulations, and Degree performed better than Topnotch or Surpass when applied in the fall, but for all herbicides the 30-day EPP application provided superior giant foxtail control to the fall application (Figure 1). The new Degree formulation of acetochlor extends giant foxtail control compared with the emulsifiable concentrate marketed as Surpass or Harness (Figure 2). At the 60-day EPP application timing, both Topnotch and Degree provided >90% giant foxtail control at 30 days after planting. There was no difference in control between acetochlor formulations at either PRE or PPI applications.

When herbicide performance was pooled across all herbicides and locations, a stairstep-shaped decrease in control occurred the earlier the herbicide application was made (Figure 3). When a fall or 60-day EPP application is desired, herbicide selection becomes more important. All six herbicides evaluated provided equivalent giant foxtail control when applied either PRE or PPI. Herbicide selection becomes more critical when applications are made long before planting.

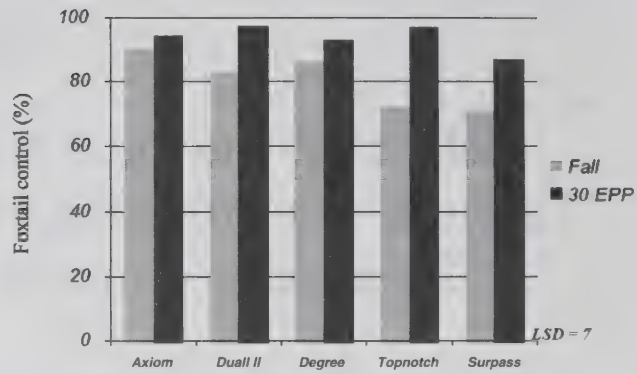

Figure 1 • Giant foxtail control (30 days after planting) provided by herbicides applied in the fall and 30 days EPP.

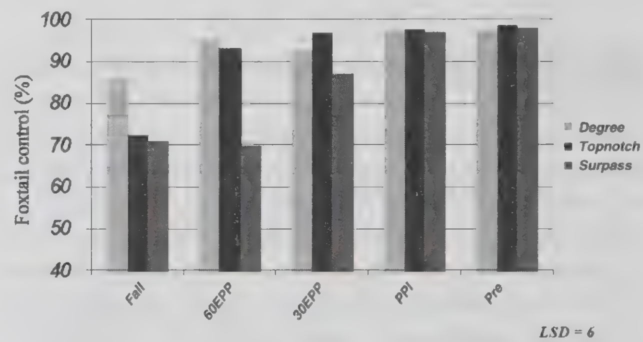

Figure 2 • Giant foxtail control (30 days after planting) provided by three acetochlor formulations applied at five application timings.

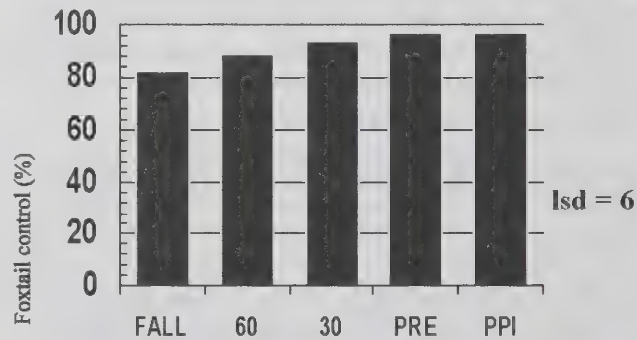

Figure 3 • Effect of application timing on giant foxtail control 30 days after planting, pooled across all herbicides.

Summary

Biopersistence, or the ability of the parent compound to exist in the soil, is an important feature of soil-applied and some postemergence herbicides and determines the suitability of EPP applications, residual weed control, and threat of off-site loss to surface or groundwater. To optimize the application timing of soil-applied herbicides, a balance between persistence and requirement for rainfall must be considered.

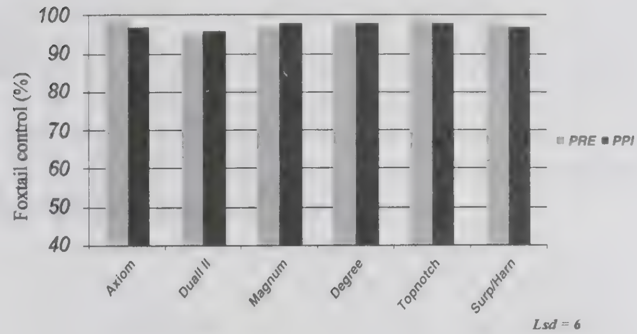

Figure 4 • Giant foxtail control (30 days after planting) provided by six herbicide formulations applied either PRE or PPI.

All Right or What's Left? A Weed Scientist in Transition

MARSHAL D. MCGLAMERY

In the summer of 1961, this Okie, who was an agronomist for a liquid fertilizer company, came to Illinois to work toward a Ph.D. in soils. I was hired to help Burns Sabey reorganize the soils teaching laboratory because Dr. Wimer had finally quit teaching soils.

So how did a "soils man" become a "weed man?" I was on a teaching assistantship with no obligations, but I needed to decide on a thesis problem. Dr. Fred Slife had a researchable problem regarding atrazine carryover to soybeans. I casually mentioned, "You need a soils person to work on that problem." Thus, I was offered the opportunity to become a "weed man!"

In 1964, Rachael Carson's *Silent Spring* was followed by a "noisy summer." The United States Department of Agriculture appropriated pesticide safety money to counteract concerns outlined in this book. I graduated in 1965 and was hired to help Dr. Ellery Knake in weeds and herbicide extension.

In 1967, I taught beginning soils at Illinois. In 1968, I taught the beginning weeds course so Dr. Slife could develop an advanced course. I taught it every year except 1971 when I was on sabbatical in Minnesota and 1998 when Dr. Steve Hart taught it. This year I taught the course again (for a total of 30 times), so I had not completely "lost my class."

In 1965, 2,4-D was the major corn herbicide. Most other herbicides such as Alanap, Amiben, atrazine, and Randox were soil applied "pre" as granules banded over the row. One issue was the width of band to use. The average band width was 12 inches (30.5 cm). Most of the corn and soybean acres were rotary hoed once and cultivated at least twice.

Randox was replaced by Ramrod (1965) and Lasso (1970), with Dual appearing in 1977, followed by Harness or Surpass (acetochlor), Frontier (dimethenamid), and Axiom. All of these "grass" herbicides were tank-mixed with atrazine for broad-spectrum weed control. The Tank-mix Age was soon followed by the Premix Age. Bicep (Dual + atrazine) was the first really successful premix, although Ramrod + atrazine, Lasso + atrazine, or Lariat were all available prior to Bicep. The Premix Age consisted of four stages: banded-alone, broadcast alone, tank-mix, and premix. A talk entitled "Premix: Fix of Nix! Can 'em and Confuse 'em?" given at several conferences and workshops was popular.

Lorox (1964) became popular for "pre" broadleaf weed control in southern Illinois soybeans. Randox and Lasso were the "pre" herbicides for grass control in corn and soybeans. You may remember Knoxweed, a mixture of EPTC and 2,4-D, or Alanap Plus, a mixture of Alanap + CIPC, used preemergence in corn and soybeans, respectively. The University of Illinois Extension publication "Using Preemergence Herbicides" (1967) was one of the first to rank herbicides by control of different weed species. The "Pre Age" had arrived.

Treflan (1965) required incorporation and thus broadcast preplant (PPI) application. Would the farmers accept this concept because it only controlled grasses and a few small-seeded broadleaved weeds? Sencor/Lexone (metribuzin [1970]) allowed a tank-mix of grass + broadleaf PPI herbicides. Sutan (1970) was mixed with atrazine for a PPI tank-mix of grass + broadleaf herbicides for corn. Research was needed to determine if incorporation should be with a tandem disc or field cultivator. Finishing discs were better

than tillage discs. Field cultivators required sweeps and speed for adequate herbicide incorporation.

Herbicide use surveys in 1972 and 1976 showed these acre changes (Sutan 4 to 29%, Lasso 14 to 40% with atrazine the primary tank-mix partner in corn, and Treflan 21 to 47% and Lasso 7 to 33% with Sencor/ Lexone being the main tank-mix partner in soybean). The PPI Age had arrived!

Basagran (1978) was the first major "post" broadleaf herbicide for soybeans. It controlled cocklebur, velvetleaf, and jimsonweed, but was poor on morningglory, nightshade, pigweed, and lambsquarters. Blazer followed and helped on all but lambsquarters. Hoelon (1975) and Poast and Fusilade (1980) provided post control of grasses in dicot crops. Atrazine + oil was the first total post weed control in corn. Bladex (1971) was tried but corn tolerance was close. Directed Lorox or Dowpon + 2,4-D were tried earlier. The first "post grass" herbicide for corn was Accent. "Total post" weed control was now available for corn and soybeans. The major issue was whether to add surfactants, oils, or fertilizer adjuvants.

Chemical weed control allowed several cultural and tillage changes, including narrow row soybeans, earlier planting of corn, less cultivation, minimum tillage, sod (no-till) planting, and double cropping. Minimum tillage, no-till planting, and double cropping were favored by the introduction of paraquat (1965) and Roundup (1978).

There were several legislative changes that affected weed control. In 1965, the Illinois Custom Operators Law was passed. The Federal Environmental Pesticide Control Act (FEPCA) (passed 1971, effective 1977) required classification of pesticides and certification of applicators and operators. The Federal Food Security Act (1985) mandated conservation tillage on highly erodible land (HEL). Herbicide use surveys of 1982 and 1995 showed these changes. Lasso in corn was replaced by acetochlor; Sutan use declined from 34 to 1% of the acres treated; Treflan use declined from 61 to 12% of the acres treated; and use of Prowl increased from 3 to 43% of the acres treated. Incorporated herbicides were losing market share.

The most recent change in weed control involves herbicide-resistant weeds and herbicide-tolerant crops. Broadleaf weed biotypes in kochia, lambsquarters, and pigweed were found to be resistant to atrazine. The increased use of acetolactate synthase (ALS) herbicides in soybeans and corn soon led to ALS-resistant waterhemp, kochia, and cocklebur. There are now indications in Illinois of ALS-resistant giant foxtail, shattercane, and ragweed.

Herbicide-tolerant crops started with the development of IMI (now CL) corn hybrids. First developed to overcome Scepter carryover, IMI corn hybrids also allowed Pursuit use in corn. IR (imidazolinone resistant) hybrids could help overcome Canopy carryover and minimize herbicide–organophosphate insecticide interaction in corn. STS soybeans (sulfonylurea tolerant soybeans) were developed to minimize Pinnacle injury to soybeans, but also were used to minimize Exceed carryover. SR/PP (sethoxydim resistant/Poast Protected) corn was developed to allow the use of Poast in corn. But the big development was Roundup Ready soybean varieties and corn hybrids to allow the use of glyphosate as a selective herbicide. Liberty Link corn and soybeans were soon developed. The Liberty gene was linked with the *Bacillus thuringiensis* gene in corn hybrids to help improve purity. Now we have the GMO (genetically modified organisms) battle.

Herbicide concerns	Potential solutions
Brown beans: atrazine carryover	Reduce rate
2.4-D drift: HVE vs LVE	No high-volatile esters
Purple corn:Treflan carryover	Reduce rate, incorporate evenly
Metribuzin-atrazine: soybeans	Reduce rate! Which herbicide?
Sutan injured some corn hybrids	Formulation safener
Banvel drift to soybeans	Adjuvants and application
Bladex injury to corn	Adjust rate, less post, no oil
Prowl pre for corn?	The cat was scratching
Black nightshade in beans	Blazer, Cobra, then Pursuit
Dual injury to corn	Safener, i.e., Dual II
Pinnacle injury to beans	STS soybeans
Post grass control in corn	Accent, then Basis
Command carryover to corn	Safener? NO!
Command drift	Command 3ME
Scepter carryover to corn	Use Pursuit
Exceed carryover to beans	STS beans?

New Developments from Industry

Notes:

Should We Expect More from Wireworms, White Grubs, Grape Colaspis, et al. in the Future?

KEVIN L. STEFFEY AND MICHAEL E. GRAY

During the past 3 years, entomologists and extension educators with University of Illinois Extension have received a conspicuous number of reports of crop injury caused by secondary insect pests of corn. Consultants, pesticide dealers and applicators, company agronomists, and growers also have noticed that billbugs, grape colaspis, southern corn leaf beetle, stink bugs, white grubs, wireworms, and other insects have been problematic in recent years. When secondary insects show up one year then do not show up again for a while, most people characterize the occurrences as "blips on the radar screen," an annual curiosity attributable to something unique that occurred that year, e.g., wet weather, late planting, excessive weediness. However, when crop damage caused by secondary insect pests seems to persist over years, people begin to take notice and ask questions. Almost immediately, speculations about the reasons for persistent problems caused by secondary insect pests begin to accumulate, for example:

- more no-till acreage than in the past,
- mild winter weather conditions,
- continuing decline of residues of chlorinated hydrocarbon insecticides in the soil,
- less use or poor performance of currently registered soil insecticides,
- poor weed control,
- delayed planting caused by wet weather, and
- more frequent field scouting disclosing the problems.

Other hypotheses probably exist. However, it is most likely that there is not a single cause for the greater incidence of crop damage caused by secondary insect pests, but rather a combination of factors, or maybe "all of the above." We do not know why the frequency of occurrence of these pests has increased recently, and we cannot predict whether the trend will continue into 2000 or disappear like ice in an oven.

So, where do we go from here? In this article, we acknowledge what we know (and do not know) about several secondary insect pests of corn, provide current research information (although little exists), offer options for management of the pests (although few are available), and speculate some more on the title of this article.

The Pests and Their Impacts

Before we discuss the pests, an explanation of the term "secondary insect pests" is in order. Some would argue that white grubs and wireworms should not be considered secondary pests. However, we use the term only to depict insect pests that occasionally cause economic damage, although typically not every year nor to a large percentage of acres. In contrast, primary insect pests such as corn rootworms and European corn borer usually cause some economic damage to a significant percentage of acres every year, although exceptions occur.

We do not have definitive values for the acreage of corn affected by secondary insect pests, percentage of corn acres treated with insecticides to control these pests, or numbers of reports of problems caused by these pests in Illinois. However, a review of our telephone-call and e-mail records revealed that

wireworms, white grubs, and grape colaspis topped the list of secondary insect pests that damaged corn in 1999. Although we focus on these pests in this article, we also provide some information about a few other secondary insect pests.

Wireworms

Many people involved with agriculture in Illinois maintain that wireworms have become a perennial problem. Although they are not present in economically damaging numbers in most cornfields, they seem to have become more prevalent in recent years. Riley and Keaster (1981) indicated that the species of wireworms that cause the most damage in Missouri are *Melanotus depressus*, *M. verberans*, and *M. lanei-opacicollis*. They also stated that other species of *Melanotus*, *Agriotes mancus*, and *Limonius dubitans* can occur in economically damaging numbers in Illinois. *Aeolus mellillus*, a creamy white wireworm, also has been found damaging corn seedlings in Illinois. All of these species and others are described in detail by Riley and Keaster (1981), the best pictorial field key to wireworms attacking corn in the Midwest.

Lefko et al. (1998b) sampled 89 Conservation Reserve Program (CRP) fields in Iowa in 1995 and 1996 to determine the incidence and diversity of wireworms. They used core sampling in 1995 and both core sampling and bait-station sampling in 1996. They recovered wireworms from approximately 45% of the fields. They found the following species of wireworms considered to have serious pest status in the Midwest: *A. mancus*, *A. mellillus*, *Hypnoidus abbreviatus*, *L. dubitans*, *M. depressus*, and *M. opacicollis*. They also recovered species of wireworms considered to have occasional pest status in the Midwest: *Conoderus lividus*, *C. vespertinus*, *Ctenicera inflata*, *Hemicrepidius hemipodus*, *H. memnonius*, *M. communis*, *M. cribulosus*, and *M. similis*. Species recovered most often were *M. similis* (64 times), *M. depressus* (25 times), *H. memnonius* (12 times), and *A. mancus* (10 times). Because they determined that bait sampling was more effective at detecting wireworm presence than core sampling, Lefko et al. (1998b) speculated that they might have recovered wireworms more frequently had they used the bait stations during both years.

Life history. Keaster and Riley (1999) briefly discussed the life history and pest status of wireworms. Female click beetles (adults) deposit their eggs in the soil of grassy areas or cultivated fields. The larvae require 1–7 years to develop into adults, depending upon species. For example, *M. depressus* and *M. verberans* remain as larvae in the soil for 3–7 years, whereas *A. mellillus* and *C. lividus* complete their life cycles in 1 year. Generations of the long-lived larvae overlap, so wireworms of all sizes and ages can be found in the soil at the same time. However, as the summer progresses and the soil becomes hot and dry, wireworms descend in the soil. Wireworms ascend in the soil profile when the temperature reaches 55°F (12.8°C) and descend when the temperature is >75°F (23.9°C). They are difficult to find during a hot, dry summer, even in heavily infested fields.

Wireworm injury often is most severe in corn planted after long-standing meadows, pastures, small grains, and forage crops. Cornfields with chronic infestations left uncontrolled for several years also may suffer heavy damage. Most damage occurs when wireworm populations contain a high percentage of mature or almost-mature larvae.

Anticipating wireworm problems. The unpredictability of the occurrence of economic levels of wireworms frustrates efforts to manage these pests. The potential for wireworm injury is significant in corn that will be planted into long-standing meadows or pastures, into fields that have been in the CRP, and after soybeans that have been double-cropped after wheat. Weedy fields and fields that are not plowed also may have larger densities of wireworms (Seal et al. 1992b). Armon Keaster (University of Missouri; personal communication) has found that adult females seem to prefer crop debris for habitation and oviposition. However, even in high-risk situations, wireworms do not always occur in numbers that will result in economic damage. Lefko et al. (1998b) recovered wireworms from less than half of the CRP fields they sampled. This uncertainty about the occurrence of wireworms, as well as their long life cycles and subterranean habitat and the lack of insecticidal "rescue" treatments, make it imperative that wireworms be detected before corn is planted if they are to be controlled.

Bait stations for sampling wireworms in the soil before planting have been recommended for >2 decades. Since the introduction of solar bait stations that incorporate corn and wheat seeds and black plastic to accelerate seedling germination (Ward and Keaster 1977, Kirfman et al. 1986), researchers have tested several other methods for sampling wireworm populations (Seal et al. 1992a, Youngman et al. 1993, Simmons et al. 1998). All have found that the corn–wheat bait is the best sampling method for wireworms. Simmons et al. (1998) stated that the corn–

wheat bait was the most efficient and effective sampling technique for determining wireworm populations in agricultural habitats and in conservation land returning to production.

Some research recently conducted in Iowa sheds additional light on the types of habitats preferred by wireworms. Lefko et al. (1998a) used wireworm presence or absence data from 1995 and 1996 and estimates of soil moisture from 89 CRP fields to estimate variables useful for identifying where wireworms are most likely to occur. The most useful variables were a soil-moisture threshold of 17% and a moisture analysis that included meteorological data from only 1 year before sampling occurred. In other words, wireworms were less abundant in soils for which the number of days >17% moisture was frequent during the previous year. Lefko et al. (1998a) coupled the variables with a hydrologic model, embedded them in a geographic information system framework, and generated a map of Story County, Iowa, indicating areas where wireworms were more likely to occur. Rice et al. (1999) generated a map of Iowa that showed areas of favorability for wireworms. However, they cautioned that such maps are relative and do not predict the presence or density of wireworms. Although use of this information may help identify areas where the potential occurrence of wireworms is great, sampling fields with corn–wheat bait stations is necessary for determining the presence or absence of wireworms.

Keaster (personal communication) reinforces the findings in Iowa. He indicated that soil particle size probably has a major impact on wireworms. Any soil that does not collapse after a rain probably supports wireworms. He also indicated that in wet springs, the corn–wheat baits may not work as well because CO_2 from the germinating seeds, which attracts wireworms to the bait, does not permeate saturated soils very well.

White Grubs

We have focused solely on so-called "true" white grubs (*Phyllophaga* spp.) whenever we discussed white grubs that damage corn. However, recent occurrences may compel us to expand our discussions to include annual white grubs such as the southern masked chafer, *Cyclocephala lurida* (formerly *C. immaculata*), and Japanese beetle, *Popillia japonica*. In 1999, we received some reports that people had found Japanese beetle grubs in fields of corn with plants exhibiting characteristic symptoms of white grub injury. Entomologists at Purdue University have some evidence that Japanese beetle grubs can cause injury to corn seedlings; however, whether the injury is consistently economic has not been determined. In addition, some observers have claimed for years that *C. lurida* grubs can cause and have caused economic damage in cornfields. However, in a greenhouse study in 1990 and 1991, Rice (1994) concluded that seedling germination, dry root weights, total dry weights, and leaf areas of corn and soybean seedlings were not affected significantly by two different densities of grubs – three and six grubs per plant. In one of the two years (1991), corn infested with nine grubs per plant had smaller leaf areas, root weights, and total plant weights. This latter discovery suggests that large densities of *C. lurida* might cause noticeable damage to corn seedlings during some years, especially if corn is planted early and seedlings grow slowly, exposing them to feeding by the grubs for an extended period of time. Whether this injury results in economic losses remains to be documented by research.

Despite our questions about the impact of annual white grubs on corn, we know that *Phyllophaga* grubs, with their 3-year life cycles, can cause significant reductions in corn plant populations and subsequent yield losses. Although we lack information about the species of *Phyllophaga* that currently cause economic problems in Illinois, our records and reports from other states suggest that the most common economically important species of white grubs that damages corn in the Midwest is *P. implicita*. Other species of white grubs collected from Illinois cornfields in the past were *P. futilis* and *P. rugosa*.

Life history. McLeod et al. (1999) discussed the life history of white grubs, and we have included aspects that pertain to white grubs in Illinois. The white grubs most damaging to corn in Illinois complete a single generation in 3 years. Each female deposits 35–60 white eggs in individual cells 1–8 in. in depth in the soil. Small, C-shaped, first instars emerge 2 to 3 weeks after egg deposition and feed on organic matter. Larvae molt once during their first summer. Grubs then move to a depth below the soil frost line. Second instars move upward and begin feeding on plant roots in the spring of the second year. Larvae feed heavily on roots the entire second summer; thus, damage usually is greatest in the second year of the life cycle. Grubs molt to the third instar by late fall and again descend in the soil. Larvae ascend in the spring of the third year and feed until mid- to late summer. Crop stand reduction as a result of feeding by true white grubs also can occur early in the third summer, although damage usually is not as extensive as during

the second year. In late July, grubs form earthen cells in which they pupate. During late August and early September, pupae transform into adults, which emerge the following spring.

Anticipating white grub problems. Similar to what we stated previously about wireworms, the unpredictability of the occurrence of economic levels of *Phyllophaga* grubs frustrates efforts to manage these pests. Almost every producer knows that the potential for injury by white grubs is significant in corn planted after pasture or grass sod. However, most reports of white grub injury in 1998 and 1999 came from individuals who found the grubs in corn planted after soybeans. A couple of astute agricultural professionals pointed out to us that a prediction of white grub damage through time could be found in Metcalf et al. (1962): "While white grubs are troublesome every year, the most severe injury occurs in regular 3-year cycles. This is because most of the insects reach the adult stage in the years 1959, 1962, 1965, and each third year thereafter. Severe damage occurs the year after the adults are abundant and lay their eggs, or the second year of the life cycle. Throughout the central and eastern United States, the years of most severe damage . . . will be 1960, 1963, 1966, and each third year thereafter." Addition reveals that 1999 was one of the "third years thereafter." Unfortunately, the predictors had no way of knowing which fields would be infested, and they did not discuss different species of white grubs.

Glogoza et al. (1998) described the types of cornfields most likely to be damaged by white grub larvae in North Dakota and suggested some sampling guidelines. They cited other literature in which the authors had concluded that a high risk of infestation of white grubs exists under continuous crop plantings when fields are near adult food sources, primarily the foliage of willow, poplar, ash, and elm. Glogoza et al. (1998) sampled soybean fields in the fall to search for larvae, pupae, and adults of *P. implicita*. They found *P. implicita* only in fields associated with shelterbelts that included willow, poplar, ash, elm, or a combination. In all fields, >90% of the *P. implicita* specimens were collected within 180 ft (55 m) of the shelterbelts; 99% or more were found within 387 ft (118 m) of shelterbelts. Larval densities declined with increased distance from the shelterbelts. They indicated that larval populations of *P. implicita* seldom would be expected to exceed treatment thresholds (most commonly one or more grub per 1 ft^2 [$0.09 m^2$]) beyond 300 ft (approximately 90 m) from the shelterbelts. They recommended that field sampling to determine the need to apply insecticides for control of *P. implicita* should take place only within 300 ft of host trees for the adults and that soil samples need not be deeper than 6 in. (15 cm). Furthermore, they indicated that sampling should not be carried out after a killing frost has occurred. *Phyllophaga implicita* grubs stop feeding when soil temperatures decrease to 15 to 16°F (–9.4 to –8.9°C).

Youngman et al. (1993) used a baited wire trap (a variation of wireworm bait stations described by Ward and Keaster [1977] and Kirfman et al. [1986]) to sample Virginia cornfields in the spring for white grubs, wireworms, seedcorn maggots, and other arthropods. The wire traps were placed in fields approximately 2 weeks before planting. Although the researchers found white grubs (e.g., Japanese beetle larvae and southern masked chafer larvae) in the traps, they were not able to develop a threshold for predicting potential stand loss in the sampled fields. Glogoza et al. (1998) indicated that spring sampling in North Dakota has not been reliable because planting may occur before a large proportion of the overwintering larvae has reached the uppermost soil layers where they can be observed.

Although research conducted in North Dakota and Virginia may not seem relevant to our cropping patterns in Illinois, we suggest that the information provided by Glogoza et al. (1998) may be useful. Forbes (1916), a well-known and respected entomologist who worked at the Illinois Natural History Survey, found that densities of white grubs were two times greater in fields located with approximately 0.2 mi (0.3 km) of host trees compared with fields >0.2 mi from trees. It seems appropriate to steal a quote from Tom Turpin's article in this *Proceedings*. Tom indicated that Pete Petty, a long-time Illinois extension entomologist, said to him during a discussion about corn insects at a regional conference: "The major problem is not that the insects have changed, it's just that every 20–25 years a new batch of entomologists comes along and they have to discover things for themselves!"

*Grape Colaspis (*Colaspis brunnea*)*

Although we anticipate some problems with white grubs and wireworms virtually every year, we seldom become concerned about grape colaspis larvae injuring corn. After all, Metcalf et al. (1962) stated: "Injury to corn [by the grape colaspis] has rarely been recorded following crops other than clover or timothy. A rotation that will avoid putting corn on spring-plowed clover or timothy sod will nearly always

prevent injury by this insect." However, some growers in central, north central, and western Illinois are becoming apprehensive about this "miniature white grub." In 1998 and 1999, several fields of corn planted after soybeans had serious infestations of grape colaspis larvae. One seed corn producer estimated a 40% stand loss caused by this secondary pest. Other corn growers also reported significant injury, and some people began considering applications of insecticides in late summer to prevent grape colaspis females from laying eggs in soybean fields. We recognize the frustration associated with pests such as the grape colaspis for which we know very little about its life history and virtually nothing about forecasting its occurrence. However, resorting heedlessly to broadcast applications of insecticides with no knowledge of timing of application or the economic impact of such applications is not advisable.

Life history. Steffey (1999a) briefly discussed the pest status and life history of grape colaspis. The grape colaspis is a sporadic pest most often found in corn planted after red clover or mammoth clover, and occasionally in corn planted after sweet clover, alfalfa, or soybeans. Injury is more severe when weather conditions retard the growth of the seedlings. The larvae feed on root hairs and may eat narrow strips from the roots. Denuded roots cannot obtain moisture and nutrients efficiently. Injury symptoms above ground include stunting, wilting, purpling of the leaves and stem (indicating a phosphorous deficiency), and browning of the tips and edges of the leaves. Severe infestations may cause plant death and reduced plant populations.

The grape colaspis completes only 1 generation per year north of 36°N latitude. It passes the winter as a small larva in the soil 8–10 in. in depth. Larvae become active early in the spring, feed on the roots of host plants, and complete their development from mid-June to early July in the Corn Belt. Pupation occurs in an earthen cell 2 or 3 in. below the soil surface. Adults emerge from the soil in July in the Corn Belt. Females lay eggs in the soil near host plants, including patches of smartweed and bull nettle. Larvae hatch in 7–14 days. Newly hatched larvae feed on roots during the latter part of summer and early fall.

Anticipating grape colaspis problems. Although Steffey (1999a) stated that damaging levels of grape colaspis occur infrequently in corn planted after alfalfa or soybeans, we may have to reconsider. Very little acreage is devoted to clover production in Illinois, so that preferred host is no longer readily available. It is entirely possible that the grape colaspis has adapted to modern corn–soybean rotation schemes to survive. If such an adaptation has occurred, we can expect to encounter grape colaspis problems more frequently in the next millennium. In addition, we probably need to learn more about weeds that might be attractive for oviposition. The literature divulges patches of smartweed and bull nettle as oviposition sites, but we wonder if other weeds might be attractive.

Billbugs and Stink Bugs

Like white grubs, wireworms, and grape colaspis, billbugs and stink bugs caused more problems in corn in 1998 and 1999 than they had in several years previously. These pests caused most of their problems in no-till cornfields, some of which had an abundance of weeds.

Life history of billbugs. Van Duyn and Wright (1999) discussed the life history of southern corn billbug (*Sphenophorus callosus*), maize billbug (*S. maidis*), and other *Sphenophorus* species. Billbugs complete 1 generation per year. The adults overwinter, primarily in protected sites along field edges. Emergence of the adults in the spring usually coincides with the time of corn planting and lasts for five or more weeks. After feeding on corn or sedges, adults mate and the females lay eggs either in the soil or in cavities eaten into plant stems. After hatching, the larvae tunnel into the root crown or into the soil where they feed in the root mass. Larvae pass through five or six instars, pupate within a chamber, and emerge in midsummer to early fall.

Adults injure corn seedlings up to the 6-leaf stage by feeding in the lower stem. Small plants die or tiller extensively if the growing point is injured; otherwise, rows of oblong holes in expanded leaves or leaves that have been cut off are the only results of adult billbug feeding.

Life history of stink bugs. Bergman (1999) provided a brief life history of onespotted and brown stink bugs, *Euschistus variolarius* and *E. servus*, respectively. Both species overwinter as adults in vegetation in or near cultivated fields. The most favorable overwintering habitats are alfalfa, wheat, or rye cover crops, or fall-seeded small grains. They complete only 1 generation per year in Illinois. Adults emerge in the spring and feed for 2–4 weeks before females begin laying eggs. Wheat and alfalfa are important spring hosts. Larvae hatch within 3 days, and nymphs develop through five instars. Older nymphs can be

found feeding alongside adults. Stink bugs usually complete their life cycle in 6–8 weeks.

Stink bug nymphs and adults have piercing–sucking mouthparts. When they feed, they inject digestive enzymes and other compounds that can be phytotoxic or cause growth abnormalities. Symptoms include lines of tiny holes surrounded by yellow to necrotic tissue, twisted leaves or stalks; tillering, stunting, and wilting; and plant death. Injury usually is most severe on small plants. As little as 1 day of feeding can result in significant reductions in grain yield.

Anticipating billbug and stink bug problems. No-till cornfields with weed problems or surrounded by vegetation in which either pest overwinters are subject to infestations. Van Duyn and Wright (1999) indicated billbugs are especially problematic to corn grown on poorly drained or organic soils. Infestations occur most frequently in nonrotated corn, along field edges, and in areas populated with nutsedge, an alternate host. The potential for billbug problems is greater in no-till corn than in fields that have been tilled. Bergman (1999) stated that the potential for stink bug injury usually increases when winter weather is mild, wheat or rye is planted as a winter cover crop, and corn is planted without tillage. Furthermore, injury is worst when planters are not adjusted properly and partially open seed slots allow the stink bugs access to the underground stem and growing point of small seedlings.

*Southern Corn Leaf Beetle (*Myochrous denticollis*)*

The southern corn leaf beetle has earned its status as a secondary insect pest of corn. The most recent (and maybe only) publication pertaining to its pest status is Kelly (1915). The southern corn leaf beetle rarely has been mentioned in extension entomology publications in the Corn Belt. However, conspicuous infestations of this pest have occurred during the past few years in Illinois, and entomologists in Missouri and Kansas observed them in 1998 and 1999. Although the acreage infested with southern corn leaf beetle has been relatively small, the insect's ability to cause significant injury has garnered some attention.

Life history. Steffey (1999b) presented a life history of the southern corn leaf beetle, primarily based upon Kelly (1915). The southern corn leaf beetle overwinters as an adult under debris and in clumps of some weed species. Adults emerge early in the spring to feed on young weed hosts, especially cocklebur, and early planted corn. After mating, the female deposits eggs in clusters of 10–50 in weed debris or in soil near corn plants. Larvae hatch in 6–10 days, and the larvae apparently feed on corn roots for about 10 weeks, from early May until mid-July in the central Corn Belt. The larvae pupate in the soil, and adults emerge from mid-July into August, depending upon latitude. After feeding for a short time, the adults seek overwintering shelter in the late summer or early fall.

Anticipating southern corn leaf beetle problems. The southern corn leaf beetle occurs most frequently in fields previously devoted to pasture or in fields that have not been cultivated for several years. The beetle also is prevalent in fields infested with cocklebur, apparently another host. Adults also have been observed feeding on smartweed, crabgrass, and sorghum (Kelly 1915). Similar to our curiosity about hosts for grape colaspis, we wonder if weeds other than cocklebur, smartweed, and crabgrass are alternate hosts for southern corn leaf beetle.

Management of Secondary Insect Pests of Corn

Management of wireworms, white grubs, grape colaspis, billbugs, stink bugs, and southern corn leaf beetle in corn is difficult, primarily because forecasting their occurrence is difficult. Several soil insecticides are registered for control of white grubs and wireworms, but determining what fields should be treated is challenging. Recent research regarding sampling of white grubs (Glogoza et al. 1998) and wireworms (Lefko et al. 1998b, Simmons et al. 1998) should help establish standard procedures for scouting for these insects. The elucidation of preferred habitats of wireworms in Iowa (Lefko et al. 1998a) should provide a foundation for similar characterizations in other states. However, a significant lack of recently conducted research hampers our ability to develop management plans for most secondary insect pests of corn. Our search for recent scientific literature pertaining to secondary insect pests of corn was limited in scope, but our findings are telling. We searched the 1990–1998 indices and the 1999 tables of contents of two of the Entomological Society of America's foremost journals, *Environmental Entomology* and *Journal of Economic Entomology*. We found only 10 articles related to secondary insect pests of corn – two about white grubs and eight about wireworms (although only four focused on wireworms in corn). We found no articles about grape colaspis, billbugs, stink bugs, or southern corn leaf beetle in these two

journals in the 1990s. This lack of current information begs for studies about secondary insect pests of corn in modern crop-production systems. In the meantime, alternatives for management of these pests are limited.

Soil insecticides

Because rescue treatments for infestations of white grubs and wireworms are not effective, the application of a soil insecticide before or during planting is the only control tactic for producers who want to plant corn and anticipate a significant infestation of either pest. Several soil insecticides are labeled for control of white grubs and wireworms, but their effectiveness varies among products and depends upon levels of infestation and environmental conditions after application.

Rescue treatments probably would not be effective against grape colaspis larvae either. Unfortunately, no soil insecticides currently are labeled for control of this pest. Assuming we could predict the occurrence of grape colaspis, application of a soil insecticide would constitute an economic risk with no guarantee of positive results.

Seed treatments

Seed treatments that contain the insecticides diazinon, lindane, permethrin, or a combination may offer some protection against wireworm attack, but currently labeled hopper-box seed treatments will not protect the roots or stems. In addition, hopper-box seed treatments will not control white grubs, grape colaspis, or any of the other secondary pests discussed in this article.

Novartis Seeds, Inc., and Zeneca Ag Products recently announced the availability of ProShield™ technology with Force® ST insecticide, a seed treatment labeled for control of corn rootworms, cutworms, seedcorn maggot, white grubs, and wireworms. For the 2000 growing season, Novartis will offer NK® brand corn hybrids with the seed already treated. Although much has been said about the potential for this seed treatment to control corn rootworm larvae, less emphasis has been placed on control of white grubs and wireworms. Unfortunately, few data regarding control of these two pests with this seed treatment exist, so producers might be left guessing about its efficacy. If the seed treatment works, producers will have a convenient tool for control of white grubs and wireworms.

Another corn seed treatment for control of several soil-inhabiting insects may be available soon. Novartis Crop Protection, Inc., is experimenting with a new neonicotinoid (proposed nomenclature) insecticide related to imidacloprid, the active ingredient of Gaucho™. The proposed trade name for the new seed treatment is Adage™, which probably will be labeled for control of wireworms and seedcorn maggot, and possibly for corn rootworms. Future research may elucidate whether the product has any activity against other secondary insect pests of corn.

Rescue insecticides

Applications of soil insecticides to prevent damage caused by billbugs, stink bugs, or southern corn leaf beetle are not recommended. Cornfields with the potential for injury caused by these pests should be scouted frequently after emergence of the seedlings from the soil. Billbugs and stink bugs can be controlled with rescue treatments, and some producers' experiences suggest that the southern corn leaf beetle can be controlled with rescue treatments, too, although no insecticide currently is labeled for control of this pest. Unfortunately, economic thresholds for billbugs, stink bugs, and southern corn leaf beetle have not been developed, so deciding when a treatment is necessary is a guessing game. We have suggested the use of economic thresholds developed for black cutworm, but this suggestion is an assumption with no supportive research data.

Transgenic corn?

Companies probably will not introduce transgenic corn for control of secondary insect pests of corn any time soon. However, use of transgenic corn for control of corn rootworms in the near future probably will have an impact on management of secondary pests. If producers switch from using soil insecticides to planting transgenic corn for control of rootworms, some insects formerly controlled with soil insecticides might cause problems because the seeds and seedlings will not be protected. This statement is speculative, but it expresses a concern producers have already.

Should We Expect More from Wireworms, White Grubs, Grape Colaspis, et al. in the Future?

No one knows the answer to this question. Three years of more-than-the-usual number of reports of

damage caused by secondary insect pests of corn has us wondering, but no one knows what will happen in 2000. We do not know whether we will experience a mild or severe winter, and we cannot predict the weather during the spring of 2000. Without this information, we are can only guess whether wire-worms, white grubs, grape colaspis, et al. will repeat their performances or exit from the agricultural stage quietly.

Undoubtedly the mild winters in recent years have benefited the survival of several secondary insect pests. We also suggest that corn grown in production systems without tillage or with reduced tillage might experience a few more problems from secondary insect pests. However, one other cultural practice also might be contributing to the increased incidence of problems caused by secondary insect pests in corn. Because many farms have become much bigger, the pressure to get the corn seeds in the ground in the spring is greater than ever in our history. Producers in Illinois and elsewhere in the Corn Belt have begun planting corn as early as possible, as early as mid-March in some areas. Soils usually are relatively cool and often wet from mid-March through mid-April in Illinois, and corn germinates and grows slowly. Every text and fact sheet ever written about corn insect pests includes the caution that early-planted and slow-growing corn plants are more susceptible to injury caused by several insects because the plants are accessible to the insects for a longer period of time. If producers continue to plant corn early into cool, wet soils, we should expect more from wireworms, white grubs, grape colaspis, et al. in the future.

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Management Options for the Southwestern Corn Borer

PHIL SLODERBECK AND LARRY BUSCHMAN

The southwestern corn borer was originally described from a specimen collected in Mexico in 1911. It was recorded in the United States by 1913 in New Mexico. By the mid-1940s, it had been found as far north as southern Nebraska and east nearly to the Missouri border. Although the northward boundary of this insect's distribution has remained about the same, it has spread eastward to the western edge of Georgia, and the range now includes part of southern Illinois.

The southwestern corn borer is a major pest of corn in the southern half of the United States. For a comparison of the developmental stages and damage caused by southwestern corn borer and another major midwestern corn pest, European corn borer, see Table 1. In most of its range, the southwestern corn borer has at least two generations per year. Although the first generation can cause serious damage, often the second generation is more abundant and receives most of the management attention. Several insecticides have been used effectively against southwestern corn borer. Also, some of the new *Bacillus thuringiensis* (Bt) corn hybrids offer a new option to decrease losses from this pest.

Description

Southwestern corn borer adults are white with light tan scales along the veins of the wings and are approximately 3/4 in. (19 mm) in length. Other than the slightly darker scales along the veins, they have no distinct markings on the wings. The wings are folded rooflike over the body when not in use. Adults are active primarily at night but can be found during the day under leaves or behind leaf sheaths.

Fresh eggs are creamy white and oval. They have a slightly convex upper surface and are a little less than 1/8 in. in diameter. Although single eggs can sometimes be found, eggs generally are laid in groups of two to five, overlapping slightly. Eggs are pressed more or less flat against the plant surface. Eggs may be laid anywhere on the plant, but most are laid on the upper surfaces of leaves. The eggs change color as they mature, developing three parallel rows of reddish orange lines a few hours after being laid.

There are two distinct color phases of southwestern corn borer larvae. During the summer, larvae are white with distinctive dark brown-to-black spots. During the fall and winter, the larvae lose their spots and become an almost uniform white. One distinguishing characteristic of southwestern corn borer larvae that can be seen even in early instars (by using a hand lens or microscope) is that the hooks (crochets) on the bottom of the prolegs form a complete circle. Other larvae commonly found on corn have a straight line or incomplete circle of hooks on the prolegs. The pupae are approximately 1 in. in length, medium to dark brown, with a blunt tail end ringed with a row of blunt projections.

Life Cycle

The southwestern corn borer has two, and sometimes three, generations per year. It overwinters as a full-grown larva in the crown or base of the corn plant just below ground level. These larvae pupate in late May

through June. The pupal stage lasts approximately 10 days, after which the adults emerge and mate and the females lay eggs. Eggs of the first generation are laid from mid-June to early July. Larvae infesting young corn move to the inner whorl where feeding damage appears as shot holes in the leaves. When the larvae are half grown, they begin to tunnel into the stalks. By mid-July, larvae begin to pupate and adults emerge to begin a second generation by late July or early August.

Most of the eggs from the second adult flight are laid in the ear zone. Small larvae feeding on tassel-stage corn can usually be found between or under the husk layers of the primary or secondary ears where they feed on the developing ear and ear shank. When the larvae reach the third instar, they bore into the stalk and begin tunneling. Sometimes larvae will bore out of the stalk and back into it one or more times, making visible exit and entry holes.

The mature larvae of the second generation tunnel or crawl down the stalks to the base of the plant and form a chamber in the crown of the plant below the soil line. In the lower portion of this chamber, the larva prepares a long cell by lining the wall with a thin layer of silk. As this cell is being constructed, the larva moves back up the stalk above the soil surface and reams the inside of the stalk until only a very thin outer shell remains. During this period, the larvae molt and lose their dark-colored spots and become an almost uniform white. The larva completes the overwintering cell by closing the upper part of the tunnel with a plug of chewed plant material and silk.

Damage to Corn

First-generation larvae feeding in the whorls of young corn plants can cause losses from dead heart (death of the growing tip) or plant stunting. Second-generation larvae cause losses by tunneling in the stalks and ears, and by girdling the stalks, which results in lodged plants.

Control Strategies

Cultural practices play an important role in managing the southwestern corn borer. Farmers can take advantage of the fact that the crown of the corn plant serves as the overwintering site for this pest. Fall or winter stalk destruction by disking, chiseling, or "middle-busting" exposes the larvae to lethal freezing and drying conditions. To be most effective in reducing the overwintering population, stalk destruction should be done in all cornfields throughout an area of several counties. Even one or two fields left undisturbed through the winter may produce enough adults to cause southwestern corn borer problems throughout the neighboring areas. We suggest that a shift to no-till or reduced tillage may lead to an increase in southwestern corn borer pressure in some areas.

On individual farms, planting date is one of the main factors that can be manipulated to reduce losses from this species. Early-planted corn is usually less susceptible to lodging than late-planted corn because early planting allows harvesting at an earlier date before girdling occurs, or at least before the corn is exposed to prolonged periods of wind, rain, and snow. Although early planting will reduce harvest losses, it will not reduce physiological losses resulting from the tunneling by larvae in the stalks.

Other helpful cultural practices include using a moderate plant population along with proper fertilization and timely and adequate irrigation. These practices ensure strong, healthy stalks that will withstand lodging conditions better than those that have been weakened by various stresses. The use of early-maturing varieties, harvest of high-moisture corn, and harvest with equipment designed to pick up lodged stalks all aid in reducing yield loss.

Some beneficial insects feed on southwestern corn borers, including lady beetles, lacewings, spiders, and at least one species of extremely tiny wasp that parasitizes the eggs. Pathogens also can have a significant impact on larval populations. Although these factors often help moderate southwestern corn borer populations, they usually do not keep populations below economic levels in areas where this insect is well established.

Insecticides are often used in areas where significant levels of southwestern corn borers are found. Generally, control efforts are aimed at the second generation because populations are higher than those of the first generation and second-generation larvae girdle the cornstalks. Proper timing of insecticide application is very important because for greatest effectiveness, the larvae must be treated after hatching but before they enter the stalk. Most chemicals require more than one application to achieve acceptable control because of the extended egg-laying period. However, high rates of some of the newer chemicals can provide adequate control with one well-timed

application. If a decision is made to apply an insecticide, avoid automatic spray schedules and base the need for additional treatments on individual field infestations of egg masses and newly hatched larvae. Insecticides for control of southwestern corn borers generally are the same as those used for European corn borer control; however, research has shown some significant differences in the efficacy of some chemicals against these two borers. Check local recommendations carefully and try other chemicals if control is not acceptable.

New corn borer-resistant corn lines may require adjustments to the treatment threshold for second-generation southwestern corn borer or may eliminate the need for insecticides. In the past few years, several hybrids have been released that contain a gene from the bacterium *B. thuringiensis* that makes them resistant to corn borer feeding. Different companies have used different strains of Bt and different promoters and have inserted the Bt genes on different chromosomes in the corn plant, thus producing different Bt events. Currently, there are five different Bt events on the market. These events differ significantly in their ability to reduce corn borer injury. The first event to be released, event 176, contained the Cry1A(b) toxin and was sold under two trade names: NatureGard (Mycogen) and Maximizer with KnockOut (originally Ciba Seeds, now Novartis). These hybrids have little or no Bt expression in the ear, and although they provide good protection against first-generation corn borers, they often do not provide good protection against second-generation European or southwestern corn borer. The events Bt-11 (Novartis) and MON-810 (Monsanto) were released under the trade name YieldGard. These events also contain the Cry1A(b) gene, but they maintain higher levels of resistance later in the season and produce some toxin in the ear. Thus, these events have excellent resistance to both first and second generations of European and southwestern corn borer, along with some suppression of corn earworm. Another event being marketed under the trade name StarLink (AgrEvo) contains the Cry9C gene. This event also provides excellent control of both generations of European and southwestern corn borer. This event is noteworthy because it contains a different source of Bt than the three other events. The last event to enter the market was DBT418; it is marketed under the trade name Bt-Xtra (DeKalb). This event is not recommended in areas where southwestern corn borer is a problem.

Table 1 • Comparison of southwestern corn borer with European corn borer.

Characteristic	European corn borer	Southwestern corn borer
Adults	Tan with brownish markings; front wings delta shaped and held flat above body when at rest.	White with tan scales along wing veins; wings approximately 3/4 in. in length; wings folded close to body when resting.
Eggs	Laid in groups of 15 to 30, mostly on the undersides of leaves. When first laid, eggs are creamy white, but as they mature, the black head of the larva begins to show through the covering of the egg.	Laid singly or in groups of 2 to 5 eggs mostly on the upper surface of leaves. The eggs are creamy white when first laid, but after approximately 24 hours, three red stripes appear across each egg. Eggs may darken before larval hatch to a yellow to reddish brown, but the red stripes can still be seen.
Larvae	Body creamy white with many small inconspicuous spots; head capsule mahogany brown to black; crochets on prolegs form an incomplete circle.	Body creamy white with conspicuous black spots (summer form, but overwintering form lacks the dark spots); head capsule medium brown; hooks on bottom of prolegs form a complete circle.
Pupae	Pupae are approximately 3/4 in. in length and are brown with a very pointed tail end.	Pupae are approximately 1 in. in length and are brown with a blunt tail end ringed with blunt projections.
Symptoms (1st generation)	Windowpane feeding to whorl.	Windowpane feeding to whorl; dead heart
Symptoms (2nd generation)	Majority of stalk boring in the middle one-third of plant; broken tassels; lodging anywhere along stalk; usually short tunnels from 1 to 4 in. in length.	Stalk boring in the bottom two-thirds of plant; fairly long tunnels from 5 to 30 in. in length; girdling at base of stalk.

Scouting Methods

Scout cornfields for first-generation southwestern corn borers from mid-May to the end of June, depending on the latitude and the year. Carefully check plants for early signs of shot-hole feeding injury on leaves and search the whorls and leaf axils of these plants for small larvae. Note that relatively small plants have no immunity or lack of attractiveness to the southwestern corn borer (as they do to the European corn borer). Plants under 15 in. (38 cm) in height are especially susceptible to serious injury or death from dead heart caused by southwestern corn borers.

Scout for the second generation of southwestern corn borer from mid-July to the end of August or until effective control measures have been used. Most eggs of this generation are laid on the upper surface of leaves in the middle portion (ear zone) of plants that are tasseling or older. Levels of infestation should be determined for each cornfield. Inspecting corn plants for egg masses requires meticulous attention and is very time-consuming.

Economic Thresholds

Thresholds for control of first-generation southwestern corn borer are not well established. Although yield reduction can occur from damage caused by first-generation larvae, damage by the first generation is not considered serious unless most of the plants are infested. In absence of a better threshold, the static European corn borer threshold of 50% of the plants infested with live larvae can be used. Because Illinois is on the northern edge of the range of the southwestern corn borer, first-generation populations often are well below economic levels.

Most insecticide treatments are directed toward newly hatched second-generation larvae. Insecticides should be applied when 20 to 25% of the plants are infested with eggs or newly hatched larvae. Scouting for second-generation egg masses should begin as soon as adults begin to emerge from first-generation pupae. If more than 20% of the plants have egg masses, consider treatment and expect to scout the field again in 10 days to 2 weeks to see if a second application may be needed. If the number of egg masses is not enough to justify treatment, scout again in 3 to 5 days, then consider treatment if the sum of the two counts is more than 25%. In this case, two applications still may be needed, so check the field again approximately 10 days after treatment to see if there are significant levels of fresh eggs or young larvae. If populations were low on the first two samplings, a third sampling should be made 7 to 10 days after the first sampling. Sum the results of all three sampling dates and treat if they exceed the 25% threshold. If the threshold is exceeded, the pressure is probably light enough to get by with a single application of an insecticide.

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Western Corn Rootworms in Soybeans: Is an Adjustment in the Economic Threshold Necessary?

SUSAN RATCLIFFE, MICHAEL GRAY, MATTHEW O'NEAL, AND KEVIN STEFFEY

Corn rootworm larval injury in first-year corn (rotated corn) was first reported in six seed production fields near Piper City, Illinois, in 1987. Initially, prolonged diapause of northern corn rootworm, *Diabrotica barberi*, was offered as the primary explanation for this injury to rotated corn. However, some of the larvae collected from affected fields were reared in the laboratory and later found to be western corn rootworms, *Diabrotica virgifera virgifera* (Levine and Gray 1996, O'Neal et al. 1997). Six years later (1993), again near Piper City, new observations of corn rootworm injury to first-year corn seed production fields were reported. Unlike the explanation offered in the mid-1980s, a shift in the ovipositional behavior of the western corn rootworm was suggested as the underlying cause of the problem. Since that first report, researchers have sought explanations for this remarkable adaptation by western corn rootworm to crop rotation, including repellency by pyrethroid insecticides, prolonged diapause, and changes in feeding preferences (Steffey et al. 1992; Levine and Oloumi-Sadeghi 1996; Spencer et al. 1998, 1999). To improve immediate management options, an economic threshold based upon adult captures in soybeans and subsequent larval injury in rotated corn was developed (O'Neal et al. 1998, 1999).

Following the reports of rootworm damage to first-year corn seed production fields near Piper City in 1993, extension specialists began recommending the use of a soil insecticide in seed production fields that had experienced damage. This recommendation later was expanded to include all first-year cornfields in the problem areas (primarily Ford, Iroquois, and Livingston counties) until an economic threshold could be developed (Gray and Steffey 1998). During 1995, larval injury in rotated corn throughout much of east central Illinois was severe. Yields declined dramatically due to severe root pruning and drought conditions that developed by midsummer. In 1996, researchers began to conduct on-farm research to develop scouting protocols and an economic threshold for adult western corn rootworm in soybean fields to assist producers in determining the need for a soil insecticide in first-year corn the following spring. Producers were asked to monitor adult western corn rootworms in soybean fields with unbaited Pherocon AM® traps. The following season, farmers left four untreated check strips (no soil insecticide) in their first-year corn during planting. In July, researchers evaluated the level of root injury in untreated strips. In general, 15 to 20 roots were dug in each untreated strip, and entomologists assessed the level of injury by using the 1- to 6-root rating scale developed by Hills and Peters (1971). Researchers used this information to establish a preliminary threshold for western corn rootworm in soybean fields. Root ratings were regressed upon the number of adults caught per trap per day to begin the determination of a preliminary economic threshold (O'Neal et al. 1998).

Development of a Preliminary Threshold

A preliminary threshold of two adults per trap per day was established to assist producers in determining the need for a soil insecticide application in first-year corn. Densities of two western corn rootworm adults in soybeans one year were predicted to result in an average root-injury rating of 3.0 (moderate root pruning) the following season. The threshold was based upon the number of adults per trap per day for a

28-day trapping period, beginning the last week in July and continuing through the third week in August. The 4-week trapping period was recommended due to the variation in peak adult emergence from year to year that results from differences in degree-day accumulations. The threshold and level of predicted injury were based upon previous research that indicated root ratings between 3.0 and 4.0 are most likely to result in economic losses. The on-farm research (14 locations) continued in 1997 and 1998; farmers used Pherocon AM traps in soybean fields in 1997, and we evaluated root injury in rotated corn during 1998. Researchers had hoped to refine the preliminary threshold based upon these data; however, the poor correlation between 1997 trapping data and the 1998 root ratings prevented any refinement of the threshold. Extension specialists at the University of Illinois continue to recommend the 12-trap scouting method with an economic threshold of two adults per trap per day. An average of seven adults per trap per day may result in an average root-injury rating of 4.0 (one node of roots destroyed).

In 1998, we prepared a Western Corn Rootworm Insect Information Sheet based upon the results from the on-farm studies. The information sheet provides producers with a brief description of the problem and identifies a nine-county area described as "high risk" for rootworm problems in corn planted after soybeans. We recommend using the 12-trap scouting method in a high-risk area to determine densities of adult western corn rootworms for decision-making purposes. An additional 13 counties are classified as "moderate risk" areas, and producers are encouraged to scout their soybean fields with the 4-trap method to determine absence or presence of western corn rootworm adults. If the traps capture a large number of western corn rootworms, producers are encouraged to switch to the 12-trap method for the remainder of the scouting period to determine densities of adult western corn rootworms for decision-making purposes.

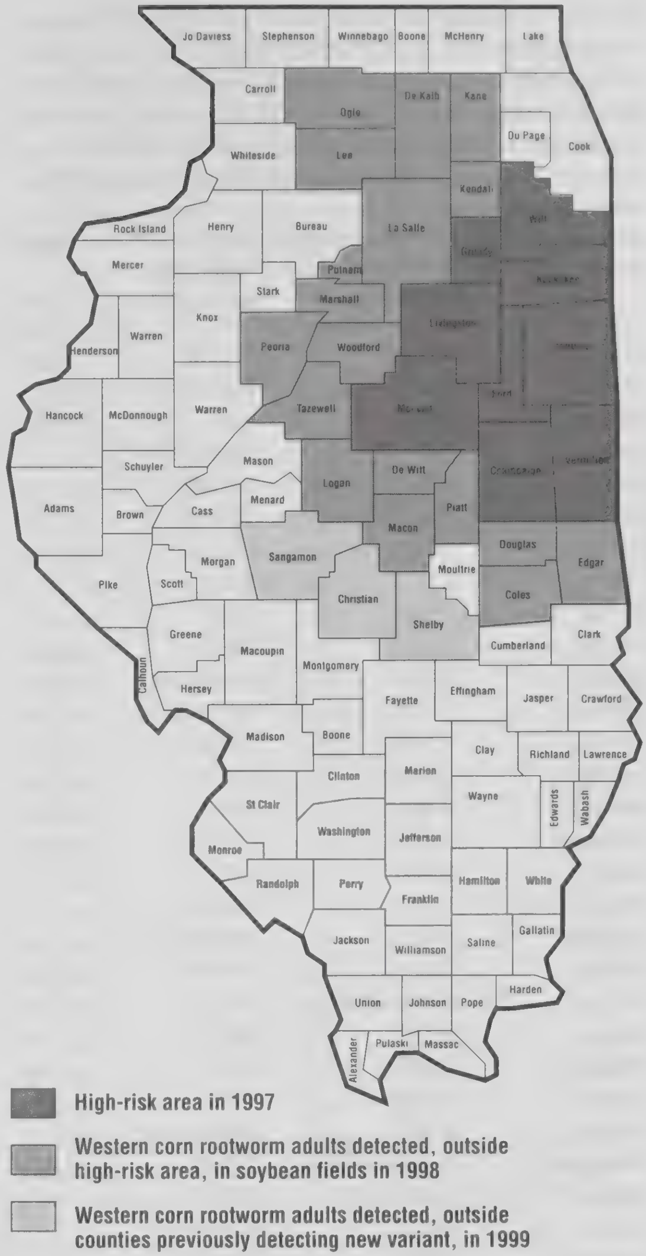

Figure 1 • Counties within Illinois where the new variant of western corn rootworm has been detected by monitoring for adults in soybean fields with Pherocon AM traps.

Scouting Soybean Fields

During July 1998, almost 5,000 copies of the insect information sheet were distributed to producers in east central Illinois. The demand for Pherocon AM traps was greater than expected, and commercial suppliers were not able to fill all orders. Some producers who were unable to obtain Pherocon AM traps used Multiguard® traps to monitor western corn rootworms. Unfortunately, the Multiguard traps are a different shade of yellow and have a greater level of attraction for western corn rootworm adults. No economic threshold has been established for Multiguard traps, so it was impossible to make an informed decision regarding the use of a soil insecticide based upon trapping data in fields where Multiguard traps were deployed. Although Pherocon AM traps can be used as a tool to enable farmers to use soil insecticides judiciously, the preliminary threshold associated with these traps should not be

Table 1 • Scouting data reported by counties as average numbers of western corn rootworm adults per trap per day in 1998 and 1999. County averages were generated from data from fields monitored with 4, 6, 8, or 12 Pherocon AM traps. The number of sites included in the calculation of county averages of adults per trap per day is listed as (n) next to the county average.

County	1998 adults/ trap/day (n)	1999 adults/ trap/day (n)
Champaign	2.12 (4)	3.72 (16)
Christian	Not Available	0.00* (5)
Coles	0.15 (4)	0.24 (2)
DeKalb	0.47 (10)	Not Available
DeWitt	1.96 (14)	2.04 (10)
Douglas	1.08 (6)	0.51 (4)
Edgar	1.92 (4)	0.41 (1)
Ford	2.95 (6)	4.75 (6)
Grundy	1.98 (5)	4.36 (1)
Iroquois	4.78 (5)	5.85 (2)
Kane	0.47 (4)	Not Available
Kankakee	3.1 (3)	Not Available
Kendall	1.15 (9)	2.18 (2)
LaSalle	1.32 (5)	3.08 (3)
Lee	0.16 (5)	1.31 (2)
Livingston	5.53 (21)	6.27 (41)
Logan	0.21 (12)	0.29 (12)
Macon	1.4 (6)	0.27 (8)
Marshall	0.46 (6)	Not Available
McLean	2.7 (44)	2.98 (59)
Menard	Not Available	0.00 (1)
Ogle	0.3 (1)	2.46 (1)
Peoria	0.3 (4)	0.01 (6)
Piatt	6.93 (8)	2.7 (5)
Putnam	0.13 (3)	Not Available
Sangamon	Not Available	0.0* (4)
Shelby	Not Available	0.02 (1)
Tazewell	0.1 (2)	0.0* (8)
Vermilion	1.93 (3)	3.36 (9)
Will	1.76 (3)	Not Available
Woodford	2.28 (7)	1.19 (18)

used to trigger adulticide treatments to soybeans (Steffey and Gray 1999).

We expanded the on-farm research project in 1998 in an effort to refine the economic threshold. The insect information sheet contains a Web site address at http://www.aces.uiuc.edu/ipm/field/corn/imr/wcrscout/wcrscout.html for reporting scouting data to extension specialists. Producers who scouted in 1998 were encouraged to report their data for inclusion in a summary to track the spread of this new variant of western corn rootworm. The response from producers was overwhelming; data from >450 fields in Illinois and Indiana had been reported by early 1999. A summary containing a subset of these data was prepared and distributed to producers by mail and at meeting held in March 1999 in Champaign, Illinois. The summary contained data from 149 fields located throughout 27 counties in Illinois. These trapping data suggested that the spread of the western corn rootworm variant was occurring faster to the north and west than had been predicted by computer models (Figure 1). Of the 27 counties from which data were reported, 11 had adult densities at or above the preliminary threshold, despite reports from Spencer et al. (1998) of a general population decline due, in part, to excessive spring precipitation in 1998 (Table 1). In 1998, of the 11 high-risk counties, Champaign, Ford, Iroquois, Kankakee, Livingston, and McLean had average daily counts of more than two beetles per trap per day. Grundy, Vermilion, and Will counties had average daily trap counts of 1.98, 1.93, and 1.76 adults per trap per day, respectively. Three counties in the moderate-risk area, DeWitt, Piatt, and Woodford, also had average daily counts of more than two adults per trap per day in 1998.

In 1999, cooperators in three counties in which scouting programs were not conducted in 1998 reported adult western corn rootworms in soybeans with the 4-trap scouting method. Menard County was the only county with cooperating producers who did not find western corn rootworms in soybean fields. In 1999, it was possible that people used sticky traps to monitor for western corn rootworm adults in soybean fields in counties outside the problem area and failed to detect western corn rootworms, but they neglected to report their scouting data to us. Based upon current reports, we suggest that the new variant of western corn rootworm has spread to 31 counties in Illinois. In addition, we have received unconfirmed reports of larval injury in first-year corn in Whiteside County in northwestern Illinois. Entomologists at Iowa State University reported larval injury to rotated corn in northeastern Iowa in 1999. Emergence cages in the suspicious field in Iowa confirmed the presence of western corn rootworm adults. Apparently the problem is spreading more rapidly than predicted.

Adjustment in Economic Threshold

Based upon the positive response by producers who attended the on-farm rootworm research workshop in March 1999, we initiated a follow-up summer root-rating project. The objective of this research effort

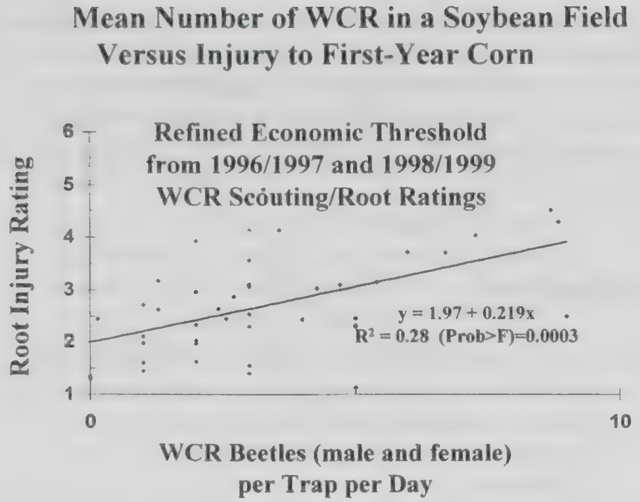

Figure 2 • Relationship between the mean numbers of western corn rootworms (WCR) (males and females) caught with 12 Pherocon AM yellow sticky traps per trap per day in a soybean field and subsequent larval injury to first-year corn. Adults were collected in 1996 and 1998, and roots were rated for larval injury in 1997 and 1999.

was to continue trying to refine our preliminary threshold. More than 100 fields were involved in this large cooperative venture. We worked with extension educators, producers, and industry personnel to coordinate the digging, tagging, transporting, and evaluations of the roots. As a result of the counts of adults in 1998 and the root-injury ratings in 1999, combined with the data collected from the 1996 and 1997 on-farm research effort, we offer a new and tentative economic threshold for western corn rootworm adults trapped in soybean fields with Pherocon AM traps (Figure 2). A regression analysis for western corn rootworm adults trapped in soybean fields predicts that a density of five adults per trap per day may result in an average root rating of 3.0 in rotated corn the following year. Ten adults per trap per day may lead to an average root rating of 4.0 in first-year corn. Data from 28 fields from seven counties were included in the 1998 and1999 data set used to generate the refined threshold (Table 2). To be included in this statistical analysis, soybean fields had to be scouted for 4 weeks with 12 unbaited Pherocon AM sticky traps, four check strips had to be established in rotated corn, and a minimum of 10 roots had to be dug and rated from each check strip (total of 40 roots per field).

Table 2 • Refinement of the western corn rootworm threshold based upon scouting and root rating data from 1996 to 1997 (not shown) and 1998 to 1999 (below). Producers' soybean fields were monitored with 12 Pherocon AM traps, and 40 corn roots (10 roots per check strip) were rated (Hills and Peters 1971) for larval injury the following season.

County	1998 beetles/trap/day	1999 root rating
Coles	0.10	1.33
DeWitt	2.10	2.95
DeWitt	1.22	1.98
DeWitt	4.34	2.43
DeWitt	3.18	2.30
Grundy	2.23	2.03
LaSalle	3.40	3.05
LaSalle	1.70	1.63
Livingston	1.30	2.71
Livingston	3.42	3.56
Livingston	4.80	1.13
Livingston	2.70	4.13
McLean	2.79	2.53
McLean	4.80	2.32
McLean	2.34	1.97
McLean	5.20	2.45
McLean	1.23	1.60
McLean	2.58	1.40
McLean	0.80	2.10
McLean	0.24	1.35
McLean	2.71	1.55
McLean	0.44	1.29
McLean	8.50	2.48
McLean	5.10	2.30
McLean	1.58	3.92
McLean	2.88	3.10
McLean	1.65	2.33
Vermilion	0.50	1.45

1999 Scouting Reports

Producers have continued to report scouting data, and the new western corn rootworm variant can be found in 31 counties in northern and east central counties of Illinois. In 1998, there were eight counties in east central Illinois with average trap counts of more than two adult western corn rootworms per trap per day. In 1999, there were 12 counties with average trap counts of more than two adult western corn root-worms per trap per day, a 50% increase from the previous year. However, as a result of the refinement of the economic threshold, only 2 of the 12 counties have average daily counts above the new threshold. A

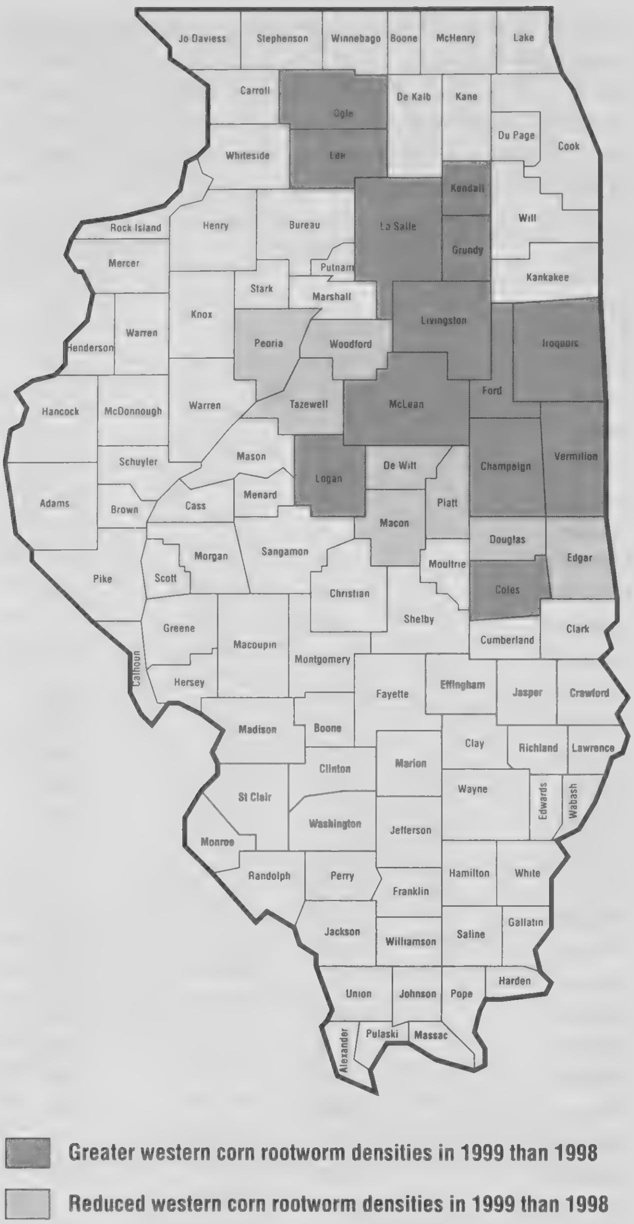

Figure 3 • Comparison of densities of western corn rootworm adults in soybeans in counties monitored in 1998 and 1999 with Pherocon AM traps.

comparison of average trap captures in 1998 and 1999 indicates that densities of adult western corn rootworms in eight counties decreased in 1999 (Figure 3). However, densities of western corn rootworms in 13 counties (primarily in east central Illinois) increased in 1999 compared with 1998 averages. These data illustrate the need to scout every field each year to make informed decisions regarding the need for a soil insecticide to control western corn rootworms in first-year corn. Although insecticide use probably will continue to escalate in first-year corn as a result of the new variant of western corn rootworm, the refinement of the threshold and the acceptance of scouting soybean fields as a valuable integrated pest management approach will assist producers in making more-informed decisions.

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Management of Insect Pests During the Past 50 Years: Lessons Learned

F. TOM TURPIN

Historical Perspective

Dealing with insect pests has been a human endeavor of long-standing. Indeed, probably forever, as the poet Odgen Nash suggests in his poem "Fleas: Adam Had'em." Consequently, insect management during the past 50 years is just the last half century of the 10,000 or so years that people and insects have done battle. And the war isn't over! As historical Illinois entomologist Stephen A. Forbes (1915) stated, "The struggle between man and insects began long before the dawn of civilization, has continued without cessation to the present time, and will continue, no doubt, as long as the human race endures."

Has our recent history in insect management taught us anything about how to deal with insects in the future? We hope so, for as the philosopher George Santayana once stated, "Those who cannot remember the past are condemned to repeat it." And a similar warning in more rural tones is found in the old saying that "Chickens always come home to roost!" My father always reminded me of that saying when I did something that resulted in undesirable consequences, especially if it was a repeated mistake. More specific to insects, long-time Illinois extension entomologist Pete Petty once remarked to me after sitting through an especially long discussion of corn insects at a regional conference, "The major problem is not that the insects have changed, it's just that every 20–25 years a new batch of entomologists comes along and they have to discover things for themselves!"

D. Price Jones (1973) in his look at the history of agricultural entomology stated that the evolution of attitudes in the development of the field is a subject worthy of study. Jones also suggested that science and technology have fashionable areas that surface from time to time. Are current efforts in insect management just fashion statements? Have past lessons gone unheeded by current insect managers? There are many lessons that we have learned during the past 50 years, but in my opinion the four lessons outlined below stand out.

Lesson 1: There is no magic bullet for managing insects

The history of insect control is replete with attempts to produce and use the magic bullet. In insect management, finding the magic bullet is a combination of finding the fountain of youth, the Holy Grail, and a lottery-winning ticket all rolled into one. No one will admit to believing that such a thing exists, but as we search for new control techniques, we are hopeful. That's the way with magic, to make it work you have to believe! To be sure, we snicker at those who suggested that entomologists would be out of business when DDT was shown to be insecticidal. But then each discovery of new insecticidal chemistry, the development of insect growth regulators, the use of an insect sex attractant, the use of sterility techniques, or the incorporation of control into target plants through genetic modification suggests a miracle cure. And we all hope that the patent shop will have to close.

Lesson 2: Mother Nature will respond

Every insect control approach is designed to interfere with natural processes. Everyone knows that you shouldn't fool with Mother Nature! At least we should understand that Mother Nature will respond. Every insect control approach will prompt a biological

response. It is not a question of if, it is a question of when. Insecticides become ineffective because the insect resists the chemical through metabolic or behavioral changes. In modern language – Resistance happens! Sterile male techniques fail because of behavioral changes in the target pest. Resistant plants are no longer resistant because the pest overcomes the resistance factor. Nonetheless, in spite of the evidence, we tend to use the "good to the last drop" approach unless forced to do otherwise by laws and regulations.

Lesson 3: Expect the unexpected

The ecosystems of this earth have yet to be understood. Consequently, any perturbation of even an agricultural crop system will result in an unexpected outcome. The classic example is biomagnification of the chlorinated insecticides, including DDT. Another example was the rapid microbial breakdown of some soil-applied insecticides that resulted in a loss of effectiveness for some uses.

The introduction of the Asian ladybeetle, because of its habit of seeking overwintering shelter in our homes, has turned this beneficial insect into what many homeowners consider a pest. With, I might add, a great number of calls to the local extension office with questions and complaints!

The introduction of genetically modified corn that produces the *Bacillus thuringiensis* (Bt) toxin created a firestorm relative to the effect of Bt corn pollen on larvae of monarch butterflies. Scientists knew that consumption of the pollen would kill the monarch larvae but apparently didn't anticipate, or care, about the potential damage to the butterfly population in the field following deployment of the Bt-producing lines of corn. The Bt corn and monarch butterfly issue has not yet been settled.

Lesson 4: There is a difference between theory and practice in insect management

It has become apparent in recent years that it is easier to develop pest management theory than it is for growers to implement the practices. For example, economic injury levels and the application of this information are so complex that the entire system is unused by growers who realize that the system is unworkable. In other instances, the in-vogue approach might involve programs that implement management across farm boundaries. Several years ago, theorists concluded that the European corn borer problem could be solved if overwintering larvae were destroyed. In theory, no overwintering European corn borers meant no egg-laying population in the spring, with the desired result of no European corn borers in the corn. So laws were passed to mandate destruction of stalks with appropriate civil penalties for those growers who did not comply. Ultimately, the program had little or no effect on the European corn borer problem, so it was dropped. But, at least in Indiana, the penalties remain on the books as a reminder of the failed effort.

Called areawide management, these programs are based on sound concepts but many times come up short because to be successful at all, some of the growers are asked to contribute beyond any expected direct return to the individual farm. Either the program has to be subsidized by outside funds, or it will fail because of lack of participation.

Have we learned anything? I'm afraid that we are continuing to make the same mistakes in insect management that we have made over the past 50 years. To be sure, the ingredients might have changed from DDT to genetically modified organisms, but the system appears much the same. First, we talk as if technology finally is the answer to a major pest situation (lesson 1) and there will be no associated problems (lesson 3). We downplay the biological reality of nature's response (lesson 2) and drag our feet at, or ignore, mandated use patterns designed to combat and delay the onset of the biological imperative (lesson 4). In this latter instance, I'd like to think that we have learned something from the past. Time will tell. We'll have to wait and see how quickly those chickens come home to roost, or if they find their way home at all!

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Pesticide Misuse in 1999 and Guidance for 2000

GERALD KIRBACH

The 1999 growing season was anything but normal for many areas in Illinois. Many producers planted corn early, whereas others delayed planting due to the wet weather. Dealers as a group were faced with customers demanding more and yet willing to pay less. By mid-May, the number of pesticide misuse complaints was considerable. The number of calls on windy days often exceeded 15.

Some areas had multiple calls from the same complainant due to concern over the application of pesticides during excessive winds. Frustration was high for the applicator as well as the complainant and the grower. The grower was faced with low prices, and the dealer was faced with a changing marketplace while trying to accomplish more within a short time frame.

We were aware that applications of pesticides, on occasion, were being made when wind speed was >20 mph. Complainants were irate due to perceived repetitive violations by an applicator with no regard to the well being of animals, gardens, organic production, or children.

Illinois Pesticide Act

The Department received many inquiries from complainants as well as applicators concerning how an enforcement action is initiated. Herein, I review the internal logistics of a misuse investigation and how to determine the appropriate action. First, let's review the rule from the Illinois Pesticide Act concerning misuse of pesticides.

Use and Violation Criteria

The following Use and Violation Criteria establish the point value which shall be compiled to determine the total violation points and administrative actions or monetary penalties to be imposed.

Category #1 – Point values based upon the loss incurred

1 point

(a) Exposure to a pesticide to plants, animals or humans with no symptoms or damage noted.

(b) Fraudulent sales practices or representations with no apparent monetary losses involved.

2 points

(a) Exposure to a pesticide which resulted in:

(1) Plants or property showing signs of damage, including but not limited to leaf curl, burning, wilting, spotting, discoloration, or dying.

(2) Garden produce or an agricultural crop not being harvested on schedule.

(3) Fraudulent sales practices or representations resulting in losses under $500.

4 points

(a) Exposure to a pesticide resulting in a human experiencing headaches, nausea, eye irritation, and such other symptoms which persisted less than 3 days.

(b) Plant or property damage resulting in a loss below $1,000.

(c) Animals exhibiting symptoms of pesticide poisoning, including but not limited to eye or skin irritations or lack of coordination.

(d) Death to less than 5 animals.

(e) Fraudulent sales practices or representations resulting in losses from $500 to $2,000.

6 points

(a) Exposure to a pesticide resulting in a human experiencing headaches, nausea, eye irritation, and such other symptoms which persisted 3 or more days.

(b) Plant or property damage resulting in a loss of $1,000 or more.

(c) Death to 5 or more animals.

(d) Fraudulent sales practices or representations resulting in losses over $2,000.

Category #2 – Point values based upon the signal word on the label

Point Value	Signal Word
1	Caution
2	Warning
4	Danger/Poison

Category #3 – Point values based upon degree of responsibility

Point Value	Degree of Responsibility
2	Accidental (such as equipment malfunction)
4	Negligence
10	Knowingly

Category #4 – Point values based upon violator's history for previous 3 years

Point Value	Record
2	Advisory letter
3	Warning letter
5	Previous criminal conviction of this Act or administrative violation resulting in monetary penalty
7	Certification, license or registration currently suspended or revoked

Category #5 – Point values based upon violation type

(1) Application oriented

Point Value	Violation
1	Inadequate records
2	Lack of supervision
2	Faulty equipment
Use contrary to label directions	
2	a. resulting in exposure to applicator or operator
3	b. resulting in exposure to other persons or the environment
3	c. precautionary statements, sites, rates, restricted use requirements
3	Water contamination
3	Storage or disposal contrary to label directions
3	Pesticide drift
4	Direct application to a non target site
6	Falsification of records
6	Failure to secure a permit or violation of permit or special order

(2) Product oriented

Point Value	Violation
6	Pesticide not registered
4	Product label claims differ from approved label
4	Product composition (active ingredients) differs from those of approved label)
4	Product not colored as required
4	Misbranding as set forth in Section 5 of the Act (4 points will be assessed for each count)

Administrative Penalties by Violation Points

Total Points	Enforcement Action
1–6 points	Advisory Letter
7–13 points	Warning Letter
14–16 points	$750.00
17–19 points	$1,000.00
20–21 points	$2,500.00
22–25 points	$5,000.00
26–29 points	$7,500.00
30 & above	$10,000.00

Analysis of Points Assessed During the 1999 Growing Season

In 1999, the Department took the following enforcement actions on the percentage of total cases indicated: Closed–No Action, 41%; Advisory Letter, 2%; Warning Letter, 40%; and Administrative Hearing, 17%.

Following is a series of tables that show the percentages of cases cited or the percentages of total cases in 1999 for which point values were assessed based upon the five categories described previously. The percentages are based upon the total of cases that warranted an action.

General Overview of 1999 Season

The Department encountered an unusually large number of pesticide drift complaints due to high wind speeds. Documentation indicated applications were made in wind speeds >40 mph. Laboratory analysis revealed the presence of compounds in plant materials that were not normal, including atrazine, Dual, Harness/Surpass, and Pursuit.

Many calls were received from complainants who were frustrated by the failure of the applicator to recognize their concerns or by demonstration of disregard. Inspectors personally notified applicators of the current conditions and concern over application, which resulted in the vehicle leaving the field of application.

There were a high number of cases that indicated a failure to follow label directions. Setback requirements were not observed. Applications were made that were in direct violation of the label-mandated wind restrictions. Operators who were stopped during applications or operators who were subsequently interviewed indicated limited knowledge of the label requirements.

Table 1 • Percentages of cases cited in category #1, point values based upon the loss incurred.

Point values for exposures	Percentages of cases cited
1	3.92
2	27.45
4	41.18
6	21.57

Table 2 • Percentages of total cases that warranted action in category #2, point values based upon the signal word on the label.

Signal word on label	Percentages of total cases
Caution	70.59
Warning	19.61
Danger/Poison	15.69

Department Actions

A review of the above-mentioned information indicates that there were a lot of cases involving high violation points due to wind conditions. The number of cases involving exposure, negligence, and use contrary to the label reflects the conditions during the 1999 growing season. The Department felt observance of setbacks, especially involving well heads, warranted citing of negligence on the part of the applicator.

The Department also made more "courtesy calls" to facilities to apprize them of potential complaints received in the office. The calls were met with mixed emotions. Applicators expressed concern due to many factors, including 1) loss of business due to customer dissatisfaction, 2) willingness of a competitor to continue to apply, 3) a diminishing "window" for pest control with the selected products, 4) being singled out by the Department, and 5) an unreasonable complainant.

Table 3 • Percentages of total cases that warranted action in category #3, point values based upon degree of responsibility.

Responsibility, point values	Percentages of total cases
Accidental, 2 points	41.18
Negligence, 4 points	47.06
Knowingly, 10 points	0.00

Table 4 • Percentages of total cases that warranted action in category #4, point values based upon violator's history for previous 3 years.

Record, point value	Percentages of total cases
Advisory Letter, 2 points	0.00
Warning Letter, 3 points	1.96
Criminal Conviction, 5 points	0.00
Suspension, 10 points	0.00

Conclusion

The Department has made every attempt to recognize all factors surrounding a pesticide misuse complaint. Every case has unique attributes that cannot always be easily resolved. Improved technology has increased the opportunity to apply pesticides; however, prudence must be used to recognize the limitations and every attempt must be made to ensure adherence to the label, minimization of exposure, and maintenance of business. The need for cooperation, partnership, and communication will increase in all facets, including education, certification, and stewardship.

Table 5 • Percentages of total cases that warranted action in category #5, point values based upon violation type.

Violation, point value	Percentages of total cases
Application Oriented	
Inadequate records, 1 point	0.00
Lack of supervision, 2 points	0.00
Faulty equipment, 2 points	1.96
Use contrary to label	
Exposure to applicator, 2 points	0.00
Exposure to others, 3 points	1.96
Precautionary statement, 3 points	21.57
Water contamination, 3 points	3.92
Storage or disposal, 3 points	0.00
Pesticide drift, 3 points	62.75
Direct application, 4 points	5.88
Falsification of records, 6 points	0.00
Failure to secure permit, 6 points	0.00
Product Oriented	
Pesticide not registered	0.00
Product label differs	0.00
Product composition	0.00
Product not colored	0.00
Misbranded	0.00

Illinois' Perspective on Total Maximum Daily Loads (TMDLs)

BRUCE J. YURDIN

Section 303(d) of the Clean Water Act (CWA) requires states to 1) identify waters that will not attain applicable water quality standards with technology-based controls alone (e.g., those that are water quality limited); 2) establish a priority ranking for such waters, taking into account the severity of pollution and the uses to be made of such waters; and 3) target watersheds for the development of Total Maximum Daily Loads (TMDLs) that would be initiated before the next biennial reporting period. As a result, the Illinois 1998 303(d) list consists of a total of 741 waterbody segments (539 stream segments, 201 inland lake segments, and 1 segment for Illinois' portion of Lake Michigan) that have been ranked within 336 watersheds. New federal regulations for the 303(d) program are currently in the offing. Highlights from these new, as yet proposed, requirements and their implications on the waterways in Illinois and the approach the state will take on the development of TMDLs are presented herein.

Introduction

The Clean Water Act (CWA) recently celebrated its 25th anniversary, but even those who track the daily activities in the field of water pollution control could tell you little of the requirements or meaning of Total Maximum Daily Loads (TMDLs). Section 303 of the CWA contains provisions for developing and revising water quality standards and for a continuing planning process that lets the U.S. Environmental Protection Agency (U.S. EPA) approve state effluent limits, areawide management plans, inventories of wastewater treatment works, and other actions the states may need to comply with the water quality standards set out in other parts of the CWA. These provisions have been actively worked on for decades, but not so for Section 303(d), the TMDL program. With the publication of proposed new regulations (40 CFR 122, 123, 124, 130, and 131) on August 23, 1999, past actions by affected dischargers, environmental interest groups, the states, and the U.S. EPA may merely be prolog for the "new world" of TMDLs about to unfold. These past actions have included the following, through September 1999:

- 17 federal court orders for the U.S. EPA to develop TMDLs if specific states fail to do so (1986–1999);
- 12 cases in which litigation was filed to compel the U.S. EPA to develop TMDLs in specified states; and
- 5 notices of intent to sue, to compel the U.S. EPA to develop TMDLs.

If litigation – and recent litigation at that – is any measure of the importance of TMDLs, then these numbers speak of the increasing value of completed and approved TMDLs. Litigation at this rate also begs the following questions: What are TMDLs? What are the implications on existing and proposed wastewater dischargers? and What effect will TMDLs have on nonpoint sources such as row crop and livestock production and construction-generated runoff? To understand these issues and the impact of the new TMDL regulations, assuming they are adopted as proposed, the Section 305(b) water quality-monitoring and evaluation process and its applicability to 303(d) must first be considered.

TMDLs and 305(b)

Under the current regulations, TMDLs are the determination of the greatest amount of loading that a water can receive without violating the water quality standards. They are, in a mathematical sense, TMDL = WLA + LA + MOS, where WLA is the wasteload allocation, or point source component; LA is the load allocation, or nonpoint source component; and MOS is the margin of safety, which must account for the limits of technical understanding and expertise in designing the TMDL. The goal of TMDLs, to achieve compliance with the water quality standards through an implementation plan designed to address all known loadings to the waterway, can be complicated by several factors:

- Changes to the water quality standards (e.g., a reduction in a currently used standard or the establishment of an entirely new criterion).
- New problems uncovered (e.g., new data on fish tissue, indicating contamination where none had been known to exist previously).
- New priorities (e.g., expansion of the monitoring program into unsurveyed streams and lakes).
- Growth and development (e.g., water quality decline may occur, even if regulated point sources are known and controlled according to existing regulations).
- Changes in environmental conditions (e.g., flow alteration due to the modification or construction of a dam).

Implementation plans, under the current TMDL construct, have been argued to be more a requirement of Section 303(e), the continuing planning process, than of Section 303(d). This is one of the many points of controversy surrounding the TMDL program, and one of the issues that has become the subject of the recently proposed TMDL regulations.

For a stream or lake to be placed on the 303(d) list, the waterbody segment must be identified as failing to meet its designated use, the prescribed use(s) to which that water may be held. Some of these uses may include aquatic life support, fishing, swimming, and drinking water. Water quality and other parameters are sampled or measured and evaluated each year for waterways in Illinois. The sampling is conducted within an overall monitoring program that can be subdivided into several sampling efforts, established for specific data needs. Some of the monitoring programs now underway are the Ambient Water Quality Monitoring Network, the Pesticide Monitoring Subnetwork, the Industrial Solvent Subnetwork, the Intensive Basin Surveys, Lake Michigan Monitoring, and Fish Contaminant Monitoring. In total, 4,000 monitoring stations across the state are used to collect data on chemical, physical, and biological parameters.

Although all monitoring networks have specific goals, locations, and time frames for sampling, one common use of the data collected is the biennial publication of the 305(b) Water Quality Report. The 305(b) Report, in short, contains data and summaries on all monitoring statewide and the identification of all assessed streams that do not meet designated uses. To arrive at this point, the collected data are reduced through further refinement and evaluation steps in which the water chemistry, sediment chemistry, and fisheries and macroinvertebrate data are classified with a relative scoring system. Over the years, several lake acreage and stream miles have been assessed (Table 1).

The 1998 data represent 83.6% of the total lake acreage and 32.7% of the total stream miles in the state. Of those waterbodies assessed, overall lake use attained full or partial support on 89.2% of the acres assessed, and streams attained full or partial status on 99.1% of stream miles assessed.

The 305(b) Report also provides an indication of water quality trends for a given waterway. Those with declining trends are identified as "threatened" and are placed on the 303(d) list. All waters that were previously identified on an earlier 303(d) list are carried over to a new list, unless a TMDL has been completed. Waters for which a sport fish consumption advisory has been issued also are included on the 303(d) list. Finally, the U.S. EPA recently required that streams identified as impaired due to nonpoint sources of pollution be included. This last factor

Table 1 • Illinois stream miles and lake acreage assessments.

305(b) Reporting cycle	Data collection period	Lake acres assessed	Stream miles assessed
1986	1984–1985	25,302	3,400
1994	1992–1993	N/A[1]	14,159
1996	1994–1995	188,243	28,454
1998	1996	188,288	28,448

[1] N/A = not applicable

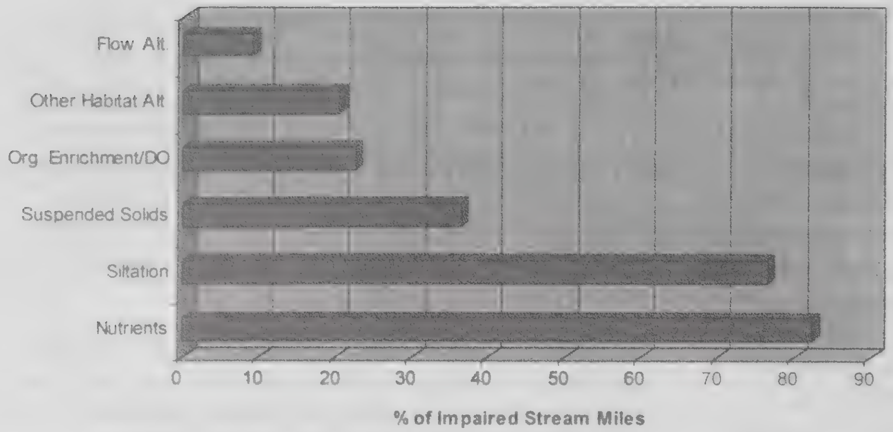

Figure 1 • Causes of impairment rivers and streams.

from the data collected and evaluated for the 305(b) Report.

According to the U.S. EPA TMDL requirements, impaired streams on the 303(d) list must be ranked as a means of determining the order in which TMDLs will be developed. States are allowed flexibility in establishing this ranking procedure. Illinois used the following method for the 1998 303(d) list. Segments with sport fish advisories were included, whereas other segments were added based on a scoring system in which the severity of pollution and the use and resource value were assigned separate numeric scores. Pollution severity was assigned a weighting factor based on the support use classification (i.e., nonsupport segments received a factor of 4). These factors were then multiplied by the stream miles or lake acreage affected. Uses and resource value were scored on the basis of the following point system:

- Illinois River and lakes >4,000 acres = 10 points
- Public water supply lakes and waters = 10 points
- Mississippi River and lakes between 2,000 and 4,000 acres = 9 points
- Water used for swimming = 5 points
- Major tributaries and lakes <1,000 acres = 4 points

The total score, and the basis for ranking these segments, is the sum of the scores for the severity of pollution and the use and value of the resource.

resulted in a major expansion of the Illinois 1998 303(d) list.

The role of a proper, comprehensive lake and stream water quality-monitoring program, as it affects the 303(d) list, cannot be understated. Lacking these data, the causes and sources of water impairment cannot be evaluated and fundamental levels of use attainment cannot be determined. Thus, the 303(d) list is the subset of waters assessed under the 303(b) stream and lake-monitoring and evaluation process that do not meet these use designations and that are therefore identified as impaired.

Figure 1 indicates the percentage of stream miles impaired by various factors as determined under the 305(b) process.

Sources of impairment are identified in Figure 2, and include agriculture, hydrologic/habitat modification, and municipal point sources as the three highest-ranked sources. Causes and sources of impairment are required data in the 303(d) list, and both are derived

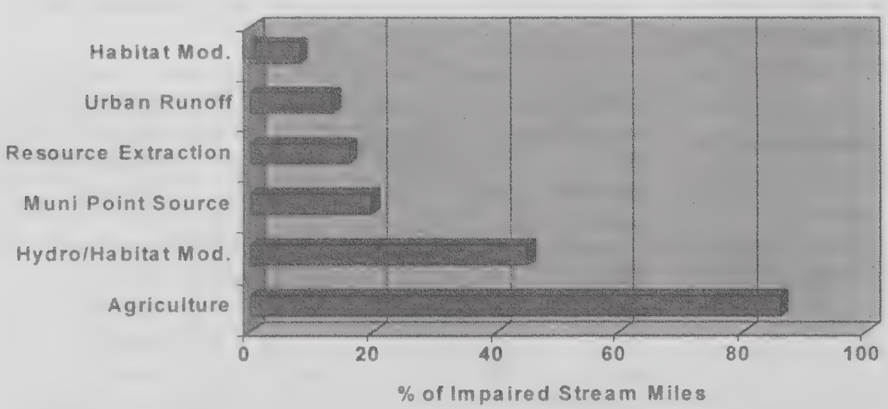

Figure 2 • Sources of impairment rivers and streams.

1998 303(d) List

The most recent submittal of the 303(d) list was approved by the U.S. EPA on August 19, 1999, and includes 741 waterbody segments – 538 stream segments, 201 inland lake segments, and Illinois' portion of Lake Michigan. Although the importance of

Table 2 • Waterbodies on the 1998 303(d) list (2-year schedule).

Waterbody	Size (miles/acres)	Rank
Busse Woods	590	4
Meachum Creek	2.89	4
Salt Creek (2 segments)	22.75 and 14.96	4
Spring Brook	3.29	4
Westbury	7.20	4
East Branch, DuPage River (5 segments)	3.18, 4.66, 8.92, 6.44, and 3.90	7
Hidden Lake	10.0	7
Lacey Creek	3.77	7
St. Joseph Creek	4.31	7
East Fork, Kaskaskia River	21.1	19
Kinmundy Reservoir	20.0	19
Cache River (4 segments)	7.25, 9.89, 2.97, and 0.12	23
Rayse Creek (2 segments)	13.05 and 16.69	24
Andy Creek	10.54	32
Big Muddy River	6.93	32
Kaskaskia River	6.42	56

the list to dischargers, potential dischargers, and users of Illinois surface waters has yet to be fully determined, the waters on the Illinois 303(d) list make up only 5% of all waters in the state. A representation of the listed waters is shown in Figure 3.

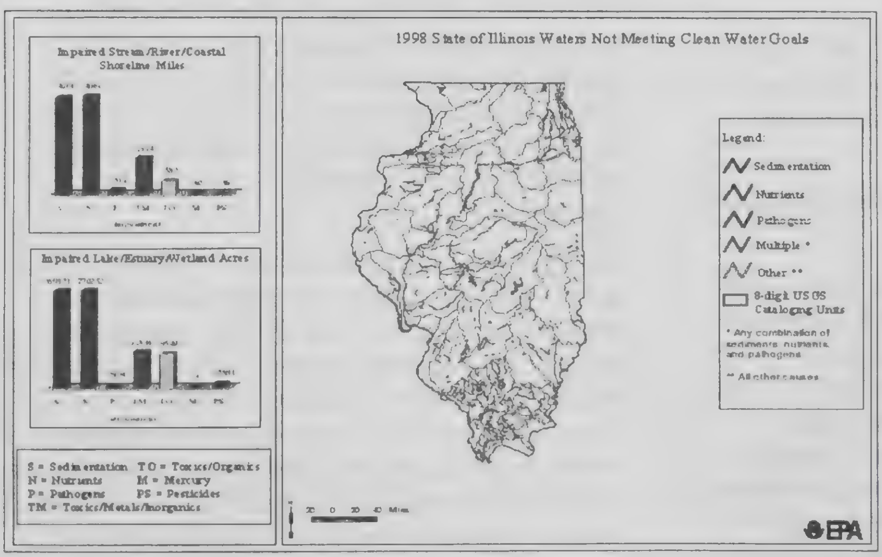

Figure 3 • 303(d) Waters in Illinois.

As approved, the 1998 303(d) list contains a schedule for the development of TMDLs that will be done over the next 2 years. That 2-year schedule contains 25 stream and lake segments within seven watersheds throughout the state (Table 2).

Additional stream segments may be on the 1998 303(d) list identified with the same waterbody name; for the purposes of Table 2, identifications have been simplified and actual locations (watershed identification codes) have not been included. Because 1998 listings are based on 1996 information, updated data are evaluated to determine trends and to establish whether these segments should remain on the updated list. This process is now underway and it is likely that several segments, including those on the 1998 two-year schedule, may be considered for delisting.

The streams on the 1998 two-year schedule were selected based on their relative rank and the complexity of the identified causes and sources of impairment. Thus, these segments do not contain historic sources (i.e., sources associated with past activities or discharges that resulted in sediment contamination or other chemical, biological, or physical modification not related to current land use practices), interstate waters, or waters affected by airborne contaminants, all of which individually or collectively could inhibit TMDL development due to a lack of practical and available technical solutions or to legal problems encountered due to vagaries in TMDL regulations.

TMDL Development in Illinois

Now that the 1998 303(d) list has been approved, work on the development of TMDLs in Illinois has begun. In May 1999, the Illinois EPA issued a request for proposals for the 25 waterbody segments on the 1998 two-year schedule. Eight bids were received from interested contractors. As of October 1999, the award of a contract(s) is imminent.

The contractor(s) will be required to develop TMDLs and implementation plans for the waterbodies with water quality, fisheries, macroinvertebrate, and

other data collected by the Illinois EPA, and with land use and other necessary data to generate a computer model of the basins in questions. These models will be designed to facilitate decisions on how best to reduce loadings to the stream or lake from point and nonpoint sources.

Over the course of the 18-month contract, three rounds of public meetings will be held. The initial meeting, to be held shortly after the contractor(s) is (are) selected, will afford the public an opportunity to hear more about TMDLs, the causes and sources of impairment for the segments on the 1998 two-year list, and the projected plans by the Illinois EPA and our contractor(s) for the coming months. Two additional meetings will be held in or near the affected basins and will be specific to those waterbody segments; one meeting will occur about midway through the contract, and one will be near the end. The later-stage meeting will allow the public to be briefed and to ask the Illinois EPA and the contractor(s) questions about the ongoing and nearly completed work to establish TMDLs and implementation plans for those basins.

Revisions to Federal TMDL Regulations

The draft regulations published on August 23, 1999, propose several key revisions to the manner in which the TMDL program will operate. Revisions also are proposed that link TMDLs to related parts of the water program under the CWA, those dealing with National Pollutant Discharge Elimination System (NPDES) permits, antidegradation provisions, and water quality standards. One of the most significant areas of contention under the existing TMDL regulations, the incorporation of nonpoint sources, has been firmly and specifically included under the proposed regulations.

The following are a few of the more significant points of the proposal made by the U.S. EPA:

- Nonpoint source management under these regulations relies on the ability of the TMDL to provide "reasonable assurance" that the plan to address the pollutant will be "implemented expeditiously" and have adequate funding to ensure a satisfactory result. Options to provide this insurance include plans that rely on state regulations; local ordinances; or performance bonds, contacts, cost share agreements, or memoranda of understanding. Regulatory alternatives are possible but not strictly mandated under this proposal.
- The degree to which the state that generates the data can decide which data should have greater value (i.e., monitored versus evaluated data) has not been clearly resolved in the draft regulations. This appears to leave open to question whether data can and should be extrapolated, and by what degree.
- The proposal applies drinking water standards (maximum contaminant levels [MCLs]) at water supplies in situations when the parameter in question cannot be applied to the waterbody. MCLs were developed to protect human health as a result of ingestion of treated drinking water, not as ambient, aquatic life protection standards. Applying MCLs in this manner appears to circumvent to procedures states use in adopting water quality standards for specific waters and their respective uses.
- Antidegradation policy affords protection of the designated uses and also applies to waters that currently exceed the standards and those that are considered highly valued. Because these waters meet or exceed the standards by definition, application of TMDLs to them appears to be an inconsistent policy. Waters that show a declining trend, whether subject to antidegradation or not, are currently evaluated for TMDLs.
- NPDES permits allow dischargers to operate within effluent limits specified under the water quality standards. Because listing a segment under 303(d) prohibits the addition of pollutants until a TMDL has been completed, renewal, modification, and issuance of a new NPDES permit may become problematic. The U.S. EPA proposes to address the NPDES issue by allowing "offsets" (i.e., effluent trading, in which a discharger may negotiate a reduction in the pollutant load with a third party). The legalities, practicalities, and manner and degree to which monitoring and permitting should be established under the offset may need further evaluation.
- In a move that will undoubtedly require an increase in the workload by the states administering the NPDES program, the U.S. EPA is reserving the option of "advancing" permits needing renewal that result in discharges to impaired waters. Currently, these permits are allowed to remain as originally issued, pending resolution of the problematic issues. Under this proposal, the U.S. EPA would require the states to move the renewal process forward, potentially requiring reductions in the established effluent limits for some dischargers.

- Certain waters under this proposal will be given "high" priority, meaning that these waterbodies will be put on a fast track for TMDL development – possibly as fast as 5 years from the adoption of these regulations – based on the presence of threatened and endangered species, the use of these waters as drinking water supplies, or the use of the waters by "sensitive aquatic species." Historic, cultural, and economic uses of the waterbody also can result in the designation of high-priority status.

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Land App and AFRAP – The Rest of the Story

WARREN D. GOETSCH

The Agrichemical Facility Response Action Program (AFRAP) and the Land Application Authorization Rule have been under some form of development, whether formal or informal, for almost a decade. The quest to find an economical yet environmentally responsible facility remediation program has proven to be both challenging and rewarding to the industry these programs are designed to serve and to the regulators who must administer them. The complicated and often frustrating web of existing state and federal laws and regulations has required detailed study, imagination, and tenacity as the AFRAP and Land Application Authorization Rule have been developed. At the time this manuscript was submitted, the Land Application Authorization Rule had been completed and the final AFRAP rule was about to be completed and submitted to the General Assembly's Joint Committee on Administrative Rules (JCAR). It is hoped that in 2000, the formal AFRAP rulemaking proposal will be well on its way to completion.

A Brief History

The Illinois state legislature created the Department of Agriculture's Land Application Authorization Program in 1989 when it provided authority to the Department to issue written authorizations to the owner or operator of an agrichemical facility for the land application of pesticide-contaminated soils at agronomic rates. This authority allowed facilities to "land farm" pesticide-contaminated soils originating from retail sites on crop production lands under specific governmental oversight. This helped to reduce the cost of a remediation project by allowing facility management to avoid the use of landfills when disposing of pesticide-contaminated soils. The program allowed the pesticide(s) present in the facility's soil to degrade naturally on cropland, just as a pesticide normally applied to farm fields would degrade during the crop season. During the past 9 years, the Department has issued >40 authorizations, allowing facilities to address pesticide contamination at these sites without experiencing the sometimes over-burdensome cost of soil disposal at a landfill. This authority was amended several times during the intervening years and now extends to soil and groundwater, as well as to pesticides and fertilizers.

In addition, the Illinois state legislature attempted to examine more closely the types of challenges that exist regarding the nature and extent of agrichemical contamination at retail agrichemical facilities when it mandated the Department to conduct a study of these sites in the early 1990s. As a result of the study published in 1993, the legislature again amended the Pesticide Act and provided for the creation of the AFRAP during the 1995 legislative session. The AFRAP was intended to provide a voluntary, industry-specific remediation program for agrichemical facilities to be administered by the Department in cooperation with a governor-appointed Board. In addition, a year earlier the General Assembly restructured the Illinois Environmental Protection Agency's (IEPA) site remediation program, which extended to all industries throughout the state via the passage of "brownfields" legislation. This restructuring ultimately resulted in the IEPA's tiered approach to cleanup objective (TACO) setting, which also has affected the Department's development of the AFRAP.

During the past several years, the Department has worked closely with the members of the AFRAP Board to review in detail the results of the 1993 contamination study and to develop formal rulemaking proposals relative to these two important programs. Many issues and obstacles have been reviewed and addressed. Some of the issues more difficult to resolve have involved the potential interaction between the AFRAP and the federal Resource Conservation Recovery Act (RCRA) as well as the interface between the AFRAP and the IEPA's Site Remediation Program.

The Department's attempt to ensure compliance with related provisions of RCRA hinges on the development of the concept of Remediation Suitability Determination Levels (RSDLs) for various pesticides that may be considered hazardous wastes in some situations. An RSDL concentration has been developed for such contaminants to allow for their participation in a land application if the pesticide concentration in the remediation media is determined to be below a certain risk-based level. If the concentration is at or above this level, the contaminated media cannot participate in the Land Application Authorization Program. This concept was patterned after the U.S. EPA's Hazardous Waste Identification Rule Proposal, which was published a few years ago. Although the U.S. EPA did not finalize the portion of the proposal that dealt with "Bright Line Numbers," the Department concludes that the concepts put forward in the proposal were valid and incorporated the concept in the Land Application Authorization Rule proposal as RSDLs.

The Department's attempt to ensure AFRAP compatibility with the IEPA's site remediation program continues at this time. The provisions of the Illinois Pesticide Act require that AFRAP projects involving groundwater contamination be coordinated with the IEPA. The Department and the IEPA have met several times to develop proper coordination meant to ensure timely and smooth project reviews. A formal memorandum of understanding between the two state agencies is under development and should provide the appropriate link between the two agencies and the two programs.

Program Status – Land Application Authorization Rule

The Land Application Authorization Program has been operating based primarily on Department policies since the provisions were added to the Pesticide Act in 1990. The Department, in cooperation with the AFRAP Board, began the development of formal rules based on these past policies in 1997. The Department formally filed a rulemaking proposal near the end of June 1998. After considering public comments and further discussions with both the IEPA and the JCAR, the Department made final revisions and proposed the second notice rule. The Land Application Authorization Program was adopted as 8 Illinois Administrative Code 258 and became effective on June 25, 1999. Since that time, the Department has received several project applications and anticipates more in the future.

Program Status – AFRAP Rule

The Department and the AFRAP Board have worked jointly on the creation of the program for almost 3 years. The challenge has been to create a program that is both environmentally responsible and economically reasonable. The program must provide similar levels of environmental protection to those of existing multi-industry programs operated by the U.S. EPA at the federal level or to the IEPA at the state level while being specific to the agrichemical industry in Illinois. The Department and the Board have attempted to incorporate concepts from these other programs while inserting data specific to the hydrogeology of Illinois and the agrichemical industry throughout the state. Several drafts have been developed and have been continually revised as we have worked with the IEPA to ensure proper coordination with other state programs, as well as compliance with applicable federal statutes. It is anticipated that the formal rulemaking process will begin before the end of the 1999 calendar year.

Summary

Both the Land Application Authorization Rule and the AFRAP are intended to provide improved, industry-specific mechanisms for the Illinois agrichemical industry to appropriately address possible pesticide and fertilizer contamination at retail sites across the state. These programs must be environmentally responsible and economically reasonable if they are to be successful. The Land Application Authorization Rule has been completed and is ready for use by the industry it was created to assist. Copies of the rule can be obtained from the Department by

telephone at 217-785-2427 (voice and TDD), or by writing the Illinois Department of Agriculture, Bureau of Environmental Programs, P.O. Box 19281, Springfield, Illinois 62794–9281. You also may contact the Department via our Web site at www.agr.state.il.us/ to request a copy of the rule.

Relative to the AFRAP, the Department remains optimistic that this program will be fully defined, the formal rulemaking process completed, and the program available for use by the agrichemical industry in the very near future.

You've Got Mail!
The Consumer Confidence Reporting Requirement

A.G. TAYLOR

You've got mail! By now all community water supply customers in Illinois should have received a copy of their respective water supply's first Consumer Confidence Report (CCR). Distribution of the report is a new federal requirement brought about by the 1996 amendments to the federal Safe Drinking Water Act (SDWA). The purpose of this report is to provide consumers with basic facts about the source and quality of their drinking water, which in turn allows them to make informed decisions regarding water consumption.

Every community water system that serves 25 or more residents or that has 15 or more service connections must produce a CCR (e.g., cities, towns, water districts, subdivisions, mobile home parks, and other entities that meet these criteria). The first report, covering monitoring data collected during calendar year 1998, or the most recent detection, if any, from the last 5 years, was due to customers by October 19, 1999. Subsequent reports are due on July 1 each year and will cover the previous calendar year. Additionally, if a community water system sells water to another water system, it must provide that satellite system with monitoring data and other relevant information that will allow the satellite to develop a CCR. The deadline for delivering such information to the satellite supply is April 1.

Contents of the Report

The content of the CCR is specified in regulations promulgated by the U.S. Environmental Protection Agency. Some of the information to be provided is mandatory and some is optional. The information required to be in the report includes the following:

- Information about the source(s) of water.
- Information about source water assessments and a summary if an assessment has been completed
- Definitions of terms such as maximum contaminant level (MCL), maximum contaminant level goal (MCLG), variance, etc.
- A table that includes the detected contaminants that are subject to mandatory monitoring, including the MCL and MCLG if appropriate for each contaminant. Results reported would be either the highest value or an average, with the range of values, depending on the method used to determine compliance.
- Likely sources of detected contaminants. (Descriptions of possible sources of the contaminants are listed in the regulations.)
- Description of any MCL violations, including duration, potential health effects, and actions taken to resolve the violations. (Specific language pertaining to potential health effects of the regulated contaminants is provided in the regulations.)
- Cryptosporidium and radon results, if monitoring was done and there were detections, with an explanation of the significance of the results.
- Description of any other violations (e.g., monitoring), including potential health effects and actions taken to resolve the violations.
- General information about contaminants in drinking water and bottled water, and information on

potential health effects for more vulnerable sub-populations.

- Sources to call for additional information and guidance regarding ways to get involved in water system decisions.

At the discretion of the water supply, the CCR also may include a table listing all nonregulated contaminants detected during the CCR reporting period, and a table listing all contaminants monitored for but not detected during that period. These tables would consequently provide information regarding potential contaminants that are not subject to the monitoring and reporting requirements in the regulations.

Distribution of the Report

The water supply must make a sincere effort to provide a copy of the CCR to all potential consumers. First, the supply must deliver a copy of its report to each customer, defined for this purpose as a billing unit or service connection to which water is delivered by a community water system. This task may be accomplished by using one of the following options:

- Direct mailing of the report to all customers.
- Including the report in a monthly newsletter that is sent to each customer.
- Hand delivering the report to each customer.
- Including the report with the water bill.

In addition to sending the report to each billing unit or service connection customer, a "good faith" effort must be made to ensure all nonbill-paying consumers (e g., apartment dwellers) receive the information. The procedures used to fulfill this requirement may include, but are not limited to the following:

- Posting the report on an Internet site accessible to the public.
- Mailing the report to all postal patrons.
- Advertising the availability of the report in newspapers, TV, and radio.
- Publishing the report in a local newspaper.
- Posting the report in public places such as cafeterias or lunchrooms of public buildings, libraries, churches, and schools.
- Delivering multiple reports for distribution by single-billed customers, such as apartment buildings or large private employers.
- Delivering the report to community organizations.

Community water systems that serve 100,000 or more people also must post their reports on a publicly accessible Internet site.

Agriculture's Concern

A significant portion of Illinois' rural population is not served by a community water system. Regardless, the announcement of the new SDWA reporting requirements generated some apprehension among the agricultural sector. The concern relates to the public extensively being made aware of contaminant detections that may be attributable wholly or in part to farming operations. It is noted that the existing regulations already require consumer notification when violations of drinking water standards occur. The new regulations broaden the scope of public notification, by means of the annual report, to include detections of contaminants that may not constitute a violation. However, the new reporting procedure is intended not only to educate the public about potential health risks of being exposed to contaminants in their drinking water but also to better inform them of actions being taken to protect against such exposures through treatment, prevention, or other means. Thus, farmers and other agricultural professionals may benefit by viewing the CCR process as a means of providing the nonfarm sector with a better understanding of agriculture's efforts in addressing the prevailing water quality problems.

Results of a Dealer Survey Regarding Best Management Practices

GEORGE F. CZAPAR, MARC P. CURRY, AND WILLIAM H. BRINK

Fertilizer and chemical dealers play a critical role in protecting water quality. In addition to following label guidelines for mixing, applying, and observing setback requirements, they have a significant impact by providing recommendations to growers.

Previous surveys have documented the importance of dealers in the pesticide selection process (Czapar et al. 1997). Illinois growers rely heavily on dealers and consultants for making pest management decisions, whereas a smaller percentage of growers base their pest management decisions directly on university recommendations (Czapar et al. 1995). A similar grower survey in Iowa found that university recommendations were deemed very important by 17% of the respondents, whereas dealer recommendations were very important to 47% of the growers (Owen et al. 1998).

Recently, a USDA publication reported primary sources of pest management information for growers in the north central region. Farm supply and chemical dealers were identified as the primary source of pest management information for 70% of the corn acres and 79% of the soybean acres (Fernandez-Cornejo and Jans 1999).

Best management practices (BMPs) have been promoted as an effective method to protect water quality (Baker and Mickelson 1994, Hirschi et al. 1997). Successful adoption of BMPs by growers requires dealer involvement and may affect pest management decisions.

To improve educational programs for Illinois fertilizer and chemical dealers, it is important to identify current sources of information, factors affecting pest management decisions, and water protection efforts that are most likely to succeed.

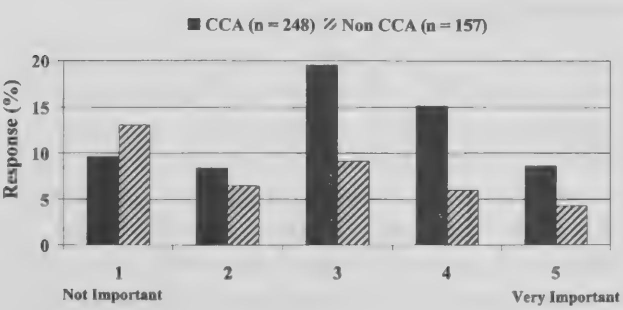

Figure 1 • How important to your customers is having a CCA at the dealership?

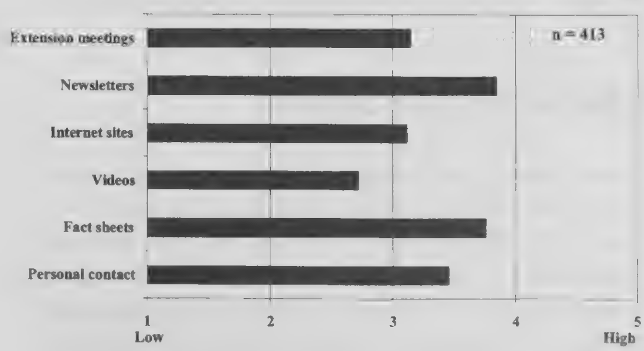

Figure 2 • What types of university programs would be the most useful to dealers and applicators?

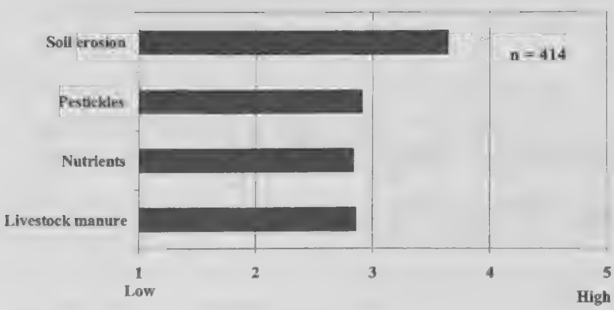

Figure 3 • Please rate the following threats to water quality in your area.

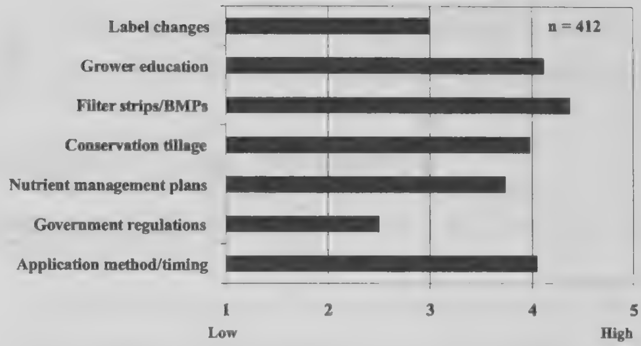

Figure 4 • Which of the following do you think would be the most successful in protecting water quality?

Survey Response

A mail survey was delivered to 793 fertilizer and agricultural chemical dealers in Illinois on March 17, 1999, and a second mailing was sent on July 16, 1999. Approximately 55% of the surveys were returned, and 422 surveys were useable. In addition to product sales, respondents reported that they provided an array of services, including custom application (96%), soil testing (94%), crop and nutrient recommendations (93%), crop scouting (86%), and geographical positioning systems (76%).

Approximately 75% of the surveys were completed by company or branch managers. Two-thirds of the respondents were midsize dealers with gross annual sales of $1–4 million. Approximately 13% of the respondents had sales of <$1 million, whereas slightly >20% had sales >$4 million.

Although 61% of the respondents identified themselves as certified crop advisers (CCAs), having a CCA at the dealership was not always ranked as being very important to their customers. Figure 1 shows the responses of CCA and non-CCAs to this question.

Information and Support

Dealers were asked to rate the importance of several sources of pest management information on a 1- (low) to 5- (high) scale. A mean score, which is the average for all responses on each question, was used to rank information sources. A mean score >3 suggests the source is rated on the high or important side of the scale.

All of the information sources identified in the survey, including company training programs, University of Illinois research and extension, and manufacturer information, received relatively high mean scores (3.7 to 3.9), indicating that dealers are using several different sources of information. Approximately 40% of the dealers provided responses to open-ended questions concerning additional sources of information. Respondents identified Purdue University (26%), Iowa State University (14%), Southern Illinois University (7%), and personal experience (4%) as important sources of information.

Fertilizer and chemical dealers also were asked to identify the types of university programs that would be most useful. As shown in Figure 2, newsletters and fact sheets were identified as the most useful resources, whereas videos were deemed less useful.

Water Quality Problems and Solutions

Dealers were asked to rate threats to water quality in their area. Survey respondents identified soil erosion as the greatest threat to water quality in their area. Pesticides, nutrients, and livestock manure were considered less of a concern (Figure 3).

When dealers were asked to identify the most successful approach to protecting water quality, filter strips and other BMPs were ranked as the best options (Figure 4). Grower educational programs and pesticide application method and timing also were identified as likely to succeed. In contrast, product label changes and government regulations were deemed less likely to succeed in protecting water quality. In addition to filter strips and BMPs, other suggestions for protecting water quality included conservation tillage practices and common sense.

To help us understand the role of manufacturers, dealers were asked to name the companies that provide the best product support and guidance on protecting water quality. Although 15 companies were identified, only three had frequencies >20%. The top-rated manufacturers were Novartis (45%), Monsanto (30%), and DuPont (25%).

Conclusions

The direct interaction dealers have with growers places them in a unique advisory position. They are locally accessible, have a financial relationship with growers, and have a direct link to product manufacturers. To retain customers, dealers also must deliver a high level of customer services.

As new water quality regulations are developed, dealers may have an increasing role in providing service related to environmental issues. To help growers adopt BMPs that are both environmentally sound and economically viable, educational support must expand.

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Making Sense in Confusing Times: Crop Variety Choices

EMERSON D. NAFZIGER

One of the first considerations as producers start the annual task of choosing the next season's set of crop varieties and hybrids – called "cultivars" herein as a convenience – is to form a realistic goal or expectation for the outcome of the process. There are often hundreds of individual cultivars that could be grown in a particular area, and the process of choosing these cultivars involves not only individual cultivar selection but also selection of the "mix" of cultivars that a grower could produce. The latter complicates the process because it involves trying to predict how the individual cultivars in the mix will complement each other. Given the thousands of possible combinations of cultivars that could be used on a farm, it is not realistic to choose the very best set, fearing disaster if each cultivar is not perfectly matched to its environment. Instead, a producer and the companies that sell seed should assess the fields, the amount of risk that the producer is willing to take and the types of risks to which he or she may be subjected, the producer's management style, and, increasingly, the market signals that exist. Then a package of cultivars can be chosen to meet these goals and conditions.

Tools Used in Making Cultivar Choices

For several decades, crop producers have been able to select new cultivars by using several tools that, when carefully applied, generally resulted in good choices. One of the primary "tools" was, and remains, the advice of the seed dealer. The knowledge of seed dealers about specific cultivars that the dealer's company sells has often varied widely, in part because companies differ in how much training and new-cultivar familiarity they offer to dealers. It was traditionally easy to become a dealer, and many farmers were dealers for various seed companies. Among these farmer-dealers, the type and degree of motivation varied widely, as did knowledge about their products and their interest in increasing sales. Recent moves by some seed companies to "professionalize" their sales force is a welcome change, and one that should improve the quality of service that crop producers will get when they choose crop cultivars.

Another tool that farmers have had is access to actual crop performance data from previous crop years. The push by some companies to take seed orders in the late summer and early fall has made such data from the current year difficult to obtain at the time of sale. And, there is the ongoing concern that data from strip trials conducted by farmers in their own fields, with cultivars chosen by the seed company with results assembled by the same company, may not be the type of comparison that is most helpful for producers as they choose cultivars. This is probably more of a structural problem than a question of credibility of the data. Companies choose the cultivars to use in on-farm strip tests, and naturally they make such choices to help demonstrate and document performance of their own cultivars, rather than to help producers make better choices among all possible cultivars. Competitor cultivars might be included, but these cultivars are chosen carefully in a way that helps the producers to form favorable conclusions about the sponsoring company's products. Such strip tests may well provide good data, but their usefulness is limited unless a producer has decided beforehand that one or more of the sponsoring company's products will definitely be purchased; thus, the strip test may help determine which one(s) should be purchased. And, because strip tests usually have only one strip of each

entry at each location, averaging data across strip tests provides much more credibility than does data from individual tests.

Another tool that has been used both by producers and by seed companies is the university-conducted testing of commercial cultivars. Approaches to such "third-party" testing differ among states, but these tests have been conducted for decades at most land-grant universities. The corn, soybean, wheat, and grain sorghum trials in Illinois are fairly typical of such programs. Entries are solicited from companies, and for each cultivar entered, the company pays a fee. Each entry at each location is randomly assigned to three or four small plots – called reps – in the field. Special equipment is used to plant and harvest each small plot, and special care is taken to ensure uniform stands and pest management. The size of these small plots typically is four rows (10 ft) in width by 20–25 ft in length; there are approximately 200 such plots per acre.

Producers who see these small plots often worry that they do not represent their field conditions well, so they conclude that these trials may not be very useful. This concern may be legitimate, but conducting the trial in this way is the only way to test 200 or more cultivars against each other in the same field. If only single strips instead of three plots (reps) of each cultivar were used, plot size could be increased. But then the ability to assess the variability in the field would be lost, and it would not be clear whether the differences were real or due to "background noise" caused by nonuniformity of field conditions. Yield and other data from such trials are given as averages over the reps. A calculated number called the least significant difference (LSD) at the bottom of the list of averages relays how large the difference between two averages needs to be before the difference is considered real and not due to chance.

Even though university trials are considered to be neutral and well conducted, they are not the only source of information that a producer should use when making cultivar choices. University crop-testing personnel cannot possibly know as much about cultivars as personnel from the company that developed or selected, then produced seed of that cultivar for sale. Companies also have access to data from strip trials, and they usually have information directly from producers who previously grew that cultivar. That does not, of course, guarantee that every company will use such data in a neutral manner, but most companies make at least some attempt to position their cultivars in a way that serves their customers well.

Recent Changes in Cultivar Selection

Although producer decisions are still made mostly by using the above-mentioned tools, there have been some recent developments that have, in some cases, made the cultivar selection process potentially more confusing. There have been several mergers of seed companies, some involving consolidation under a "life science" company that also might sell herbicides or other crop inputs. The coupling of cultivar selection with that of other crop inputs may restrict cultivar selection, or at least may make it difficult to consider the full range of cultivars. Some companies also do not enter cultivars in university trials, so getting neutral information on cultivars may be impossible.

In addition, there has been a great deal of uncertainty thrown into the cultivar selection process by the introduction of genetically modified (GM) traits into crops. The GM traits that are available now were moved into existing crop cultivars with the backcross method that starts with a developed cultivar and crosses the desired trait from the donor parent into the already-developed cultivar in a process that takes 3 to 4 years at minimum. In the process, some other genes from the donor parent always end up in the resulting GM cultivar, and sometimes these genes decrease the yield or negatively affect other agronomic characteristic of the GM cultivar. When the backcross procedure results in lower yield potential than the improved cultivar had initially, this outcome is referred to as yield drag. The genes responsible for yield drag are seldom known, so predicting or preventing yield drag often is impossible.

There is little evidence that most GM traits released so far have caused yield drag on their own. But GM cultivars often have some yield lag – the GM cultivar generally is no better in agronomic performance than the cultivar from which it was developed, whereas newer cultivars released may well outperform both the original parent and the GM cultivar. Over time, as entire breeding programs are converted to using only genetic material containing a particular GM trait, breeding for yield and other agronomic characteristics can proceed without the need to backcross, and the yield lag associated with earlier releases tends to decrease.

A very real question remains without a complete answer: Do GM cultivars differ in yield and other agronomic characteristics from non-GM cultivars? It is more difficult than it first seems to answer this question. Initially, there was a lot of rapid turnover in GM hybrids and varieties; early releases often were made with whatever cultivars were available, perhaps following fewer-than-normal backcross generations, under pressure to get the GM crop seed out quickly to compete with that of other companies. Sometimes, a GM cultivar was sold for only 1 year before it was dropped or replaced; thus, tests designed to show differences between GM and non-GM crops often were not able to use a consistent or representative group of GM cultivars.

It is also sometimes difficult to conduct good GM versus non-GM tests. For example, companies that sold Roundup-resistant cultivars often indicated that these cultivars were to be treated only with Roundup. Thus, the cultivar types – with and without resistance to Roundup – had to be treated with different herbicides and this approach may have introduced bias. There were some releases of "counterpart" hybrids and varieties, which most tests showed to have comparable performance. But the cultivar used as the recurring parent in a backcross conversion never ends up with only the desired gene crossed in; even after 10 or more crossing generations, some genes from the donor parent persist, and these genes can cause the plant to perform differently than normal.

The current data comparing GM and non-GM crops are somewhat mixed, with GM cultivars yielding less in a few cases, but with little difference in most cases. We can probably conclude that there is more variability within the top groups of non-GM and GM cultivars than there is between these groups. Thus, it will pay to be very careful in choosing cultivars no matter what specific genetic characteristics have been bred into the group of cultivars from which the choices are made.

One concern that has been expressed by some is that the time and effort it has taken to cross GM traits into crop cultivars has meant an interruption in overall breeding progress. That could be true, but if so the interruption was probably relatively short, and it is unlikely that it will be noticeable as we look back on the late 1990s. Still, choices of cultivars with the desired GM characteristics often are much more restricted than were choices before GM crops existed.

Despite the confusion that has been brought into the cultivar selection process, the tools of selection remain the same, and some of the consolidated companies might have the ability to provide better selection services to producers than did the smaller companies from which they were formed. One factor has not changed: the risk of choosing the wrong cultivars is real, and the cost of choosing the wrong cultivar is high. Thus, the investment of time and energy in choosing cultivars will continue to produce a high return.

Of Monarchs and Men: Reflections on Bt Corn for 2000

MARLIN E. RICE

Farmers had their first opportunity in 1996 to plant transgenic, or genetically modified, corn hybrids that killed European corn borer, *Ostrinia nubilalis*. Transgenic corn contains a modified gene from the soil bacterium *Bacillus thuringiensis* that produces a protein that is toxic to some insects when the protein is eaten. Scientists isolated the protein-producing gene, modified it, and inserted it into corn (Koziel et al. 1993). This transgenic corn is commonly called Bt corn and the protein it produces causes European corn borer larvae to die after they feed on the plant. This protein prevents large amounts of leaf feeding, stalk tunneling, and subsequent yield loss caused by European corn borer.

The European corn borer is one of the most damaging insect pests of field corn in the United States with yield losses and control expenditures costing farmers >$1 billion annually (Mason et al. 1996). Two generations of this insect usually occur throughout the Corn Belt. A single first-generation larva tunneling in whorl-stage corn can cause a 5 to 6% yield loss; a second-generation larva tunneling in blister or dough-stage corn can cause a 2 to 3% yield loss (Bode and Calvin 1990). Yield losses caused by second-generation European corn borers in 18 insecticide trials over a 7-year period in Iowa ranged from 0.9 to 32.6 bu/acre more than in the untreated controls (Rice 1994a,b,c, and unpublished data); 16 of the 18 fields (89%) had yield losses that exceeded 4 bu/acre. The average yield loss caused by these second-generation borers was 9.3 bushels, but actual yield loss may have been greater than observed because insecticides rarely provide 100% control.

Iowa and Minnesota farmers' perceptions about damage caused by European corn borer were that yield losses were much larger than observed in the Iowa trials. Sixty-five percent and 69% of farmers thought that first- and second-generation larvae, respectively, caused serious economic yield loss (Rice and Ostlie 1997). Their perception was that first-generation damage averaged 15.2 bu/acre and second-generation damage averaged an additional 15.3 bu/acre, for a total of 30.5 lost bu/acre. Ironically, only 35.2% of the farmers had scouted their fields and used economic thresholds, and even fewer (28.7%) had used an insecticide for control of European corn borer.

Rice and Pilcher (1998) suggest that there are numerous potential benefits of Bt corn to the farmer. These benefits include control of European corn borer larvae, protection of yield against insect loss, reduced insecticide use and hazards associated with handling, reduced insect control costs, proper timing of insect control, environmental safety, reduced field scouting costs, areawide suppression of European corn borer, some control of minor insects such as stalk borer and corn earworm, reduced amounts of volunteer corn and subsequent herbicide use in soybean, reduced frequency and incidence of ear rot and stalk rot, and reduced harvest loss.

There also are potential limitations to the use of Bt corn (Rice and Pilcher 1998). These limitations include unpredictability of the size of the European corn borer population; payment of the Bt technology fee, which does not guarantee an economic return; variable yield performance of Bt hybrids; marketing restrictions of Bt grain; development of resistance of European corn borer; and perceived environmental risks.

Table 1 • Performance of YieldGard (event Bt11 and MON810) hybrids in Iowa, 1997–1999.

	Yield protection		No yield protection	
Year	% of hybrids	Avg. yield /acre[a]	% of hybrids	Avg. yield /acre[a]
1997[b]	40.3	18.3 bu	3.5	– 5.5 bu
1998[c]	23.9	12.2 bu	4.5	–14.2 bu
1999[d]	21.4	9.1 bu	7.0	–11.5 bu

[a] Significantly different from hybrid pair at $P \leq 0.1$.

[b] $n = 57$ Bt and non-Bt hybrid pairs (Cargill, DeKalb, Golden Harvest, Pioneer) in 14 counties.

[c] $n = 67$ Bt and non-Bt hybrid pairs (DeKalb, Golden Harvest, Novartis, Pioneer) in 16 counties.

[d] $n = 14$ Bt and non-Bt hybrid pairs (DeKalb, Golden Harvest, Mark, Pioneer) in six counties.

The value of genetically engineered crops is currently being debated in public and Gianessi and Carpenter (1999) state that it is imperative that the rationale for the use of these biotechnology crops be discussed. They suggest that farmers adopt and use crop protection technology for several reasons: 1) it provides cost-effective solutions to pests that, if left uncontrolled, would lower yields; 2) it is used to control pests that are inadequately controlled with existing technologies; and 3) it is less expensive than current methods with equivalent control. The new technology may not be adopted, however, if it is not competitive with existing control methods. Others, however, view genetically engineered crops as hazardous to the environment and suggest greater legislation with tighter restrictions or even the elimination of this technology (Rissler and Mellon 1996).

The damage potential of the European corn borer and the use of Bt corn as a management option necessitate a review of this biotechnology. I discuss four issues relative to Bt corn: Bt hybrid yields, reduced insecticide use, perceived environmental risk, and economic decisions.

Bt Hybrid Yields

A variety of Bt hybrids expressing YieldGard® technology (genetic events Bt11 or MON810) were evaluated in Iowa during the past 3 years. NatureGard® (event 176) and StarLink® (event CBH351) technologies were evaluated in 1998 and 1999, respectively. Hybrids were evaluated at 14 locations in 1997, 16 locations in 1998, and 6 locations in 1999. Bt hybrids were evaluated against genetically similar, non-Bt commercial hybrids. All hybrids were replicated three to five times in large-scale field plots 4–12 rows in width and 200–2,200 ft in length. Yields were taken with a combine, adjusted to 15.5% moisture, and subjected to analysis of variance with the P = 0.1. If the Bt hybrid statistically yielded more than its genetically similar non-Bt hybrid, then it was considered to provide yield protection. If the Bt hybrid statistically yielded less than its non-Bt hybrid then it was considered to provide no yield protection. Results are shown in Tables 1–3.

The YieldGard hybrids showed yield protection, or protected against yield loss caused by European corn borer, in 21.4–40.3% of the hybrid comparisons. The average yield protection from these Bt hybrids ranged from 9.1 to 18.3 bu/acre. A small number of Bt hybrid comparisons, 3.5–7.0%, resulted in a yield loss of 5.5–14.2 bu/acre. The NatureGard hybrids had one comparison each where there was a significant

Table 2 • Performance of NatureGard (event 176) hybrids in Iowa, 1998.

	Yield protection		No yield protection	
Year	% of hybrids	Avg. yield /acre[a]	% of hybrids	Avg. yield /acre[a]
1998[b]	16.7	18.8 bu	16.7	–10.2 bu

[a] Significantly different from hybrid pair at $P \leq 0.1$.

[b] $n = 6$ Bt and non-Bt hybrid pairs (Mycogen) in six counties.

Table 3 • Performance of StarLink (event CBH351) hybrids in Iowa, 1999.

	Yield protection		No yield protection	
Year	% of hybrids	Avg. yield /acre[a]	% of hybrids	Avg. yield /acre[a]
1999[b]	0.0	0 bu	40	–7.1 bu

[a] Significantly different from hybrid pair at $P \leq 0.1$.

[b] $n = 5$ Bt and non-Bt hybrid pairs (Garst) in five counties.

Table 4 • Bt farmer survey question: How many acres of field corn did you plant in 1998 and how many of those acres were planted to Bt corn in 1998?

State	Mean ± SE acres field corn (*n*)	Mean ± SE acres Bt corn (*n*)
Illinois	476.3 ± 26.0 (305)	166.5 ± 10.4 (302)
Iowa	324.7 ± 9.8 (843)	129.0 ± 5.2 (825)
Kansas	349.1 ± 46.5 (63)	115.3 ± 13.1 (63)
Minnesota	370.2 ± 14.7 (490)	182.8 ± 8.9 (485)
Nebraska	489.5 ± 28.9 (201)	190.5 ± 14.0 (197)
Pennsylvania	176.2 ± 32.5 (34)	62.6 ± 21.9 (34)
Mean*	375.4 ± 7.9 (1936)	153.3 ± 4.0 (1906)

* Mean is an overall average from the original data set, not a mean of the columns.

yield protection (18.8 bushels) and another with a yield loss (10.2 bushels). The StarLink hybrids showed no yield protection but two evaluations resulted in a yield loss of 7.1 bu/acre.

Bt corn farmers in six states planted on the average 41% of their acres to Bt corn in 1998 (Table 4). They, too, are seeing variable performance of their Bt hybrids and not all the results are positive. Exactly 7% rated the Bt hybrid as producing less yield and this averaged 14.7 bushels, whereas 44.9% of the Bt hybrids were rated as producing higher yields on the average of 10.3 bushels (Tables 5 and 6).

Yield performance of Bt hybrids shows some variability and not all situations show a yield protection that translates into more grain in the bin. Several items are worth noting. First, grain yield is a function of many genes and not all hybrids are created equally. It appears, based on the limited data for the StarLink hybrids, that the insertion of the Bt gene did not result in better yielding hybrids. Second, European corn borer populations during the study were moderately large during 1997, but then declined to historically low densities during 1998. Fall populations for 1999 have not yet been determined, but summer populations appeared to have been very small again. With very small populations of European corn borer, few or no yield differences would be expected between a Bt and non-Bt hybrid. The YieldGard data from 1997 through 1999 show such a trend in declining yield differences between the Bt and non-Bt hybrids, probably as a result of smaller insect populations not causing yield reductions in the non-Bt hybrids.

Reduced Insecticide Use

Insect management with Bt corn has reduced the amount of handling and application of synthetic insecticides. Results from 3,334 Bt corn producers in a 1997 survey from six states showed that 29.5% of these farmers were planting Bt corn with the intent of eliminating insecticide use for European corn borer control. During a 5-year period (1991–1995), 30.6 and 15.3% of the Bt corn producers had used insecticides for first- and second-generation control, respectively. The average number of years (out of five) that they had used insecticides against European corn borer was 2.6 and 2.4 years for first and second generations, respectively. When asked about insecticide use for European corn borer control during 1997, 19.3% said insecticide use against this pest decreased and only 5.5% said it increased.

The same survey queried 1,967 farmers in 1998 and found similar results (Tables 7–10). A notable exception was that the percentage of Bt corn farmers using less insecticide increased from 19.3 to 26% (Table 10). These surveys suggest that Bt corn is replacing the use of synthetic insecticides for European corn borer control.

Perceived Environmental Risks

The Environmental Protection Agency (1995) stated that wildlife and insect predators occurring in Bt corn should not be adversely affected by the Bt protein. This position is supported by an Iowa State University study (Pilcher et al. 1997) where Bt corn pollen

Table 5 • Bt farmer survey question: How would you rate the grain yields of Bt corn compared with similar maturity non-Bt hybrids you planted on about the same date? (circle answer and please notice secondary questions).

Option	IL (309)	IA (850)	KS (63)	MN (498)	NE (201)	PN (35)	Mean (1956)
Lower	8.1	7.2	9.5	4.4	10.0	2.9	7.0
Similar	47.6	42.2	30.2	33.0	47.8	45.7	41.2
Higher	40.1	41.2	57.1	56.0	34.9	39.9	44.9
I don't know	4.2	8.4	3.2	6.2	7.5	11.4	7.0

Answers are presented as percentages.

Table 6 • Bt farmer survey question: If the yields were lower, how much lower were they (bu/acre); or if they were higher, how much higher were they (bu/acre)?

State	Bu/acre lower yields Mean ± SE (*n*)	Bu/acre higher yields Mean ± SE (*n*)
Illinois	14.9 ± 2.4 (24)	9.2 ± 0.5 (114) I
owa	14.0 ± 1.5 (60)	9.8 ± 0.4 (331)
Kansas	12.0 ± 2.1 (6)	8.4 ± 0.9 (30)
Minnesota	15.1 ± 3.5 (22)	11.7 ± 0.4 (264)
Nebraska	17.8 ± 3.7 (20)	10.5 ± 0.9 (66)
Pennsylvania	1 (1)	9.1 ± 0.0 (12)
Mean	14.7 ± 1.1 (133)	10.3 ± 0.2 (817)

was fed to three of the most common European corn borer predators, green lacewing, *Chrysoperla carnea*; the insidious flower bug, *Orius insidiosus*; and the twelvespotted lady beetle, *Coleomegilla maculata*. Bt corn pollen was not toxic to any of these predators and it did not delay development of immature stages or decrease longevity of adults. In field studies (Pilcher et al. 1997), pollen from Bt corn also did not affect these predators and population densities were similar in both Bt and non-Bt cornfields.

More recently, a study from Cornell University (Losey et al. 1999) showed that pollen from Bt corn may have toxic effects on larvae of the monarch butterfly. The caterpillar, or larval stage, of this insect feeds on milkweed. Because some milkweed grows next to corn in the Midwest, Bt corn pollen may drift onto milkweed and affect monarch larvae. Losey et al. (1999) coated milkweed leaves with Bt corn pollen and allowed the monarch larvae to feed. After 4 days, 44% of the monarch larvae died that fed on the Bt pollen coated leaves, whereas none died on the leaves dusted with non-Bt pollen. The Cornell monarch study was widely regarded as both preliminary and scientifically flawed (Beringer 1999, Hodgson 1999, Rice 1999, Shelton and Rousch 1999), yet it received significant attention by the national media proclaiming the hazards of biotechnology.

A study at Iowa State University (Hansen and Obrycki 1999) supports the preliminary findings of Losey et al. (1999). At Iowa State, potted milkweed plants were placed in and adjacent to Bt corn and non-Bt corn. The highest concentration of pollen was found on plants within the cornfield, as might be expected. Leaf samples were taken from the milkweed within and adjacent to the field and used to assess mortality of newly hatched larvae. Within 48 hours, there was 19% mortality in the Bt corn pollen treatment compared with 0% on non-Bt corn pollen-exposed plants and 3% in the control, which had no pollen.

Is Bt corn a serious problem for monarchs? Both studies suggest that some, but not all, monarch caterpillars may be killed when they eat Bt corn pollen. It is not known whether monarch larvae can avoid eating pollen on a milkweed in a natural environment or whether corn pollen is evenly distributed on all leaves on a milkweed. No studies have been conducted to assess the actual mortality of monarchs on milkweed near cornfields. Also, not all acres of corn are planted to Bt hybrids; estimates for 1999 suggest that 30% of the acres in the Corn Belt were planted with Bt corn.

It is important to remember that the monarch studies are preliminary and monarch mortality has not been

Table 7 • Bt farmer survey question: During the 5-year period of 1991–1995 (before Bt corn was introduced), what steps did you take to minimize yield losses from European corn borers? (circle all that apply and please notice secondary questions).

Option	IL (309)	IA (858)	KS (63)	MN (500)	NE (202)	PN (35)	Mean (1967)
Insecticide (1st generation)*	22..3	16.4	27.0	24.8	49.5	34.3	23.5
Insecticide (2nd generation)*	14.6	6.8	38.1	11.2	37.1	2.9	13.2
Resistant hybrids	29.8	26.6	7.9	33.8	21.3	34.3	27.9
Planting dates	5.2	4.3	1.6	2.8	5.9	2.9	4.1
Harvest early	39.2	36.8	12.7	42.2	27.2	28.6	36.7
Nothing	36.2	49.1	28.6	37.6	27.2	40.0	41.1
Other	4.5	2.6	17.5	3.2	5.0	5.7	3.8

Data are presented as percentages.

* See Table 8.

Table 8 • Bt farmer survey question: Out of those 5 years (see Table 7), how many years did you use an insecticide against first-generation (first-brood) infestations; and out of those 5 years, how many years did you use an insecticide against second-generation-(second brood) infestations?

State	Mean ± SE years 1st generation (*n*)	Mean ± SE years 2nd generation (*n*)
Illinois	2.2 ± 0.2 (67)	1.8 ± 0.1 (44)
Iowa	2.2 ± 0.1 (126)	1.5 ± 0.1 (57)
Kansas	3.1 ± 0.5 (14)	4.0 ± 0.3 (22)
Minnesota	1.6 ± 0.1 (120)	1.5 ± 0.1 (53)
Nebraska	3.4 ± 0.1 (92)	2.6 ± 0.1 (73)
Pennsylvania	4.5 ± 0.3 (11)	2.0 (1)
Mean	2.4 ± 0.1 (430)	2.1 ± 0.1 (250)

Mean (±SE) years an insecticide has been used against both first- and second generations

documented in the field. But if a farmer is concerned about the possibility of monarch mortality from Bt corn pollen, then during the next planting season the potential impact of Bt corn on monarch larvae could effectively be reduced or eliminated by planting the border rows and end rows to a non-Bt corn hybrid. This planting pattern effectively moves the Bt hybrid away from the field edge and reduces or eliminates the amount of Bt pollen that drifts out of the field and onto nearby milkweed. These border and end-row plantings also could serve as part of the European corn borer refuge that is necessary for helping to delay the development of European corn borer resistance to Bt corn. On the positive side, the planting of Bt corn has reduced the amount of broad-spectrum insecticides applied to corn and this should be beneficial not only to the monarch but also to many other insect species.

Economic Decisions

The decision for many farmers to purchase and plant Bt corn in 2000 will be determined solely by economics. Bt corn in the past has been sold at a premium price compared with non-Bt hybrids, and if this continues in view of depressed market values, then any added technology fee must be weighed as a cost versus a potential benefit because an economic return is not guaranteed. An economic return for Bt corn will be realized only if the density of European corn borers is large enough to cause economic loss greater than the premium paid for the Bt hybrid. A large number of European corn borer eggs laid in a field increases the protective value of Bt corn. However, if a low density of adults results in very few eggs deposited in a Bt cornfield, then the

Table 9 • Bt farmer survey question: What was your primary reason for planting a Bt corn hybrid in 1998? (circle all that apply)

1 Prevent yield loss from European corn borer
2 Eliminate field scouting for European corn borer
3 Eliminate need of insecticide for European corn borer control
4 Previous experience with the company's hybrids
5 University performance field trials
6 Seed company performance field trials
7 Neighbor's experience with Bt corn
8 Other, please list ________

Option	IL (309)	IA (858)	KS (63)	MN (500)	NE (202)	PN (35)	Mean (1967)
1	80.3	81.5	66.7	86.2	81.2	82.9	82.0
2	10.0	7.8	12.7	13.6	14.9	0	11.2
3	24.9	22.4	44.4	39.2	42.6	14.3	27.1
4	18.4	16.1	17.5	19.4	12.9	31.4	17.3
5	8.4	11.3	6.3	9.4	5.4	8.6	9.6
6	20.4	22.3	23.8	22.0	16.8	31.4	21.6
7	7.1	9.8	4.8	12.6	9.4	14.3	10.0
8	5.8	7.9	12.7	7.8	5.4	2.9	7.4

Data are presented as percentages.

Table 10 • In 1998, did insecticide use for European corn borers on your farm increase, stay the same, or decrease when compared to insecticide use trends during the past 5 years?

Option	IL (296)	IA (814)	KS (60)	MN (474)	NE (193)	PN (33)	Mean (1873)
Decreased	25.0	19.4	35.0	28.5	50.3	6.1	26.0
Stayed same	22.3	17.7	25.0	13.5	16.1	45.4	17.9
Increased	2.4	2.0	1.7	3.4	2.6	0	2.4
Didn't use	50.3	61.3	38.3	54.6	31.1	48.5	53.7

Data are presented as percentages.

economic investment was unnecessary and no benefit can be expected.

One of the dilemmas is that population densities of European corn borers are unpredictable. In 1998, European corn borer populations dropped to historically low levels in Minnesota and Wisconsin. A similar trend probably occurred in Iowa and Illinois although data are not available. Populations did increase slightly during 1999, but they are still small. Even with this knowledge, predicting what the population will do in 2000 is nearly impossible. Winter, and especially wind and rain in the spring during egg laying can reduce a population to almost zero. Therefore, it is nearly impossible to predict insect populations and the subsequent impact they might have on grain yield.

One method to measure the potential benefit of a technology is to estimate the gain threshold (Higley and Pedigo 1996). The gain threshold calculates the potential yield loss caused by European corn borers that is necessary to justify the management cost (i.e., the expense of a Bt hybrid technology fee). The gain threshold is calculated as $G = C/V$, where G is gain threshold expressed as bushels per acre, C is cost of management in dollars per acre, and V is market value in dollars per bushel. For instance, with a technology fee of $5.00/acre and corn market value at $2.00/bu, then a 2.5 bu/acre yield protection (i.e., not lost to European corn borers) would be needed to break even on the investment. Gain threshold values are shown in Table 11 for a range of management costs and crop values. Note that as the market value of corn decreases against a high technology fee, the number of bushels needed to pay for the investment also increases.

Marketing restrictions also must be factored into the cost–benefit equation. As Balter (1997) predicted, public perception regarding the safety of transgenic crops may cause local operators of grain elevators to refuse Bt corn and some importing countries may refuse grain delivery from transgenic crops, thereby limiting potential markets for U.S. farmers.

Conclusion

Transgenic Bt corn has changed dramatically the way many farmers manage European corn borer. Test results show that some Bt corn hybrids show excellent yield protection and are a valuable pest management tool when European corn borer populations reach moderate or large densities. According to surveys, most Bt corn farmers are satisfied with Bt corn performance. A few farmers continue to scout their non-Bt corn acres and apply an insecticide only when necessary, a pest management tactic that has proven to be successful but not widely adopted by most farmers. For others, there is still the option of planting a Bt hybrid. But technology fees, low market

Table 11 • Gain thresholds for four different Bt hybrid technology fees at three corn market values.

Technology fee $/acre	Market value $/bushel	Gain threshold bu/acre
2.50	$1.75	1.4
"	$2.00	1.3
"	$2.25	1.1
5.00	$1.75	2.9
"	$2.00	2.5
"	$2.25	2.2
7.50	$1.75	4.3
"	$2.00	3.8
"	$2.25	3.3
10.00	$1.75	5.7
"	$2.00	5.0
"	$2.25	4.4

prices for corn, perceived hazards to nontarget organisms such as monarchs, unpredictable European corn borer populations, and potential import restrictions for the grain may make this option less palatable in 2000.

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Status of Transgenic Crops for Control of Insects other than European Corn Borer

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The soil-inhabiting bacterium *Bacillus thuringiensis* (Bt) has long been recognized as an insect pathogen. Thousands of strains have been identified, which are effective against different kinds of insects. The *B. thuringiensis* genes responsible for producing insect-specific toxins have been isolated and incorporated into crops such as potatoes, cotton, and corn. This article focuses on control of caterpillar pests with Bt corn. Some of the information presented herein was derived from personal communications with the following entomologists: R. T. Bessin, University of Kentucky; P.M. Davis, Monsanto Corporation, Des Moines, Iowa; J. W. Van Duyn, North Carolina State University; J. M. Whalen, University of Delaware; and H. R. Willson, The Ohio State University.

There are several kinds of Bt corn on the market (Table 1). All are derived from *B. thuringiensis* var. *kurstaki*. The type of protein toxin produced by the transgenic corn determines which insects can be potentially controlled. The actual "event" when *B. thuringiensis* genes were incorporated into the corn plant affects where and how much toxin is produced, thereby influencing insect control. The yield potential of Bt corn hybrids is determined by the agronomic quality of the corn hybrid, not by the presence of *B. thuringiensis*. Bt hybrids can only prevent losses from certain insects, they cannot increase the yield potential.

The first Bt transgenic corn hybrids were developed to control European corn borer, *Ostrinia nubilalis*

Table 1 • Transgenic corn for control of fall armyworm.

Bt protein	Tradename (event)	Toxin expression	Reduction in ear damage[1]	Reduction in whorl damage[2]	Source
Cry1A(b)	Knockout (176)	leaves, pollen	2	4	DeLamar et al. 1999b
Cry1A(b)	YieldGard (Mon810)	whole plant	2	4	Benedict et al. 1998
Cry1A(b)	YieldGard (Mon810)	whole plant	2	3	DeLamar et al. 1999a
Cry1A(b)	YieldGard (Mon810)	whole plant	2–3	3–4	DeLamar et al. 1999b
Cry1A(b)	YieldGard (Mon810)	whole plant	4	2–4	DeLamar et al. 1999c
Cry1A(b)	YieldGard (Mon810)	whole plant	—	3	van Duyn, pers. comm.
Cry1A(b)	YieldGard (Bt11)	whole plant	—	3	van Duyn, pers. comm.
Cry1A(b)	YieldGard (Bt11)	whole plant	1–2	2	DeLamar et al. 1999a
Cry1A(b)	YieldGard (Bt11)	whole plant	3	3–4	DeLamar et al. 1999b
Cry1A(b)	YieldGard (Bt11)	whole plant	—	3	Williams et al. 1997

[1] Primarily fall armyworm damage, some corn earworm (1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control).

[2] The defoliation score was recorded on a non-numeric 0–9 scale, so this reduction in defoliation score is not a true percentage (100* (1 – (Bt defoliation score/standard defoliation score))). (1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control). Van Duyn data are based on percentage of plants fed upon.

(Hübner), in the Midwest. Corn hybrids in which the toxin is expressed throughout the plant are virtually immune to European corn borer. In years and in regions where European corn borers are abundant, the use of Bt corn can increase farm profitability.

Table 2 • Transgenic corn for control of corn earworm.

Bt protein	Tradename (event)	Toxin expression	Reduction in ear damage[1]	Source
Cry9C	Starlink (CBH351)	whole plant	2	Higgins et al. 1999
Cry1A(b)	Knockout (176)	leaves, pollen	1	Higgins et al. 1999
Cry1A(b)	YieldGard (Mon810)	whole plant	2–3	Higgins et al. 1999
Cry1A(b)	YieldGard (Mon810)	whole plant	2	Riley et al. 1999
Cry1A(b)	YieldGard (Bt11)	whole plant	4	Higgins et al. 1999
Cry1A (b)	YieldGard (Bt11)	whole plant	3	Riley et al. 1999

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

Control of Insects Other than European Corn Borer

Table 3 • Transgenic corn for control of armyworm.

Bt protein	Tradename (event)	Toxin expression	Reduction in plant damage[1]	Source
Cry1A(b)[a]	YieldGard (Mon810)	whole plant	5	Whalen, pers. comm.
Cry1A(b)	Knockout (176)	leaves, pollen	3	Pilcher et al. 1997

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

Table 4 • Transgenic corn for control of black cutworm.

Bt protein	Tradename (event)	Toxin expression	Reduction in plant damage[1]	Source
Cry9C	Starlink (CBH351)	whole plant	1	Shaw et al. 1998
Cry9C	Starlink (CBH351)	whole plant	4	Bessin, pers. comm.
Cry9C	Starlink (CBH351)	whole plant	2	Willson, pers. comm.
Cry1A(b)	Knockout (176)	leaves, pollen	1	Pilcher et al. 1997
Cry1A(b)	YieldGard (Mon810)	whole plant	1	Bessin, pers. com.
Cry1A(b)	YieldGard (Mon810)	whole plant	1	Willson, pers. com.
Cry1A (c)	BT Xtra (DBT418)	whole plant	1	Bessin, pers. comm.

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

The efficacy of Bt corn against other corn insect pests, and the economic benefit of using Bt corn against these pests, is not well understood. Bt corn has been evaluated for control of at least nine other insects. In this article, efficacy is described by comparing the performance of a particular event to non-Bt hybrids in the same experiment (Tables 1–9). The following scale was used to standardize efficacy across different methods and locations: 1 = slight or no suppression, 0–20% reduction in insect damage relative to the non-Bt control; 2 = fair suppression, 20–50% reduction in insect damage relative to the non-Bt control; 3 = good suppression, 50–70% reduction in insect damage relative to the non-Bt control; 4 = moderate control, 70–90% reduction in insect damage relative to the non-Bt control; and 5 = excellent control, >90% reduction in insect damage relative to the non-Bt control.

Fall armyworm, *Spodoptera frugiperda* (J.E. Smith), is partially controlled by Bt corn (Table 1). The extent of control varies with location and with experiment, from little suppression to moderate control. Corn that expresses the *B. thuringiensis* toxin throughout the plant provided better control than event 176, which expresses the toxin only in the leaves and pollen.

Similar results are observed for corn earworm, *Helicoverpa zea* (Boddie), with control ranging from slight suppression to moderate control (Table 2). Greatest reduction in ear damage seems to occur in corn with the Bt11 event.

Excellent control of armyworm, *Pseudaletia unipuncta* (Haworth), has been observed with the Mon810 event (Table 3). These results were from no-till corn planted into small grain that had been burned down with a herbicide. Results might be different for large, migrating armyworms (Whalen, personal communication). The Knockout gene, event 176, provided moderate suppression of armyworm.

The Cry9C protein, expressed in Starlink hybrids, gave moderate control of black cutworm, *Agrotis ipsilon* (Hufnagel), in one test, and fair suppression in another (Table 4). Other kinds of Bt corn had little effect on black cutworm. Fair suppression of western bean cutworm, *Richia albicosta* (Smith), damage to ears (Table 5) was observed in Colorado in corn expressing the Cry1A(b) protein (Mon 810, Bt11, and 176 events). No suppression was observed with corn expressing the Cry1A(c) protein. Bt corn, event 176, gave fair suppression of stalk borer, *Papaipema nebris* (Guenée) (Table 6).

Corn that expresses the toxin throughout the plant provided excellent control of southwestern corn borer, *Diatraea grandiosella* Dyar (Table 7). Corn that has limited expression of the toxin (leaves and pollen only, event 176) gave little to good suppression of southwestern corn borer. The Mon810 event gave excellent control of sugarcane borer, *Diatraea saccharalis* (F.) (Table 8). Not surprisingly, Bt corn does not control Banks grass mite, *Oligonychus pratensis* (Banks) (Table 9).

In summary, Bt corn gave greatest control of crambid borers such as sugarcane borer and southwestern corn borer. Bt corn suppressed or gave moderate control of noctuid pests such as fall armyworm, corn earworm, and armyworm.

Table 5 • Transgenic corn for control of western bean cutworm.

Bt protein	Tradename (event)	Toxin expression	Reduction in ear damage[1]	Source
Cry1A(b)	YieldGard (Mon810)	whole plant	2	Peairs et al. 1999
Cry1A(b)	YieldGard(Bt11)	whole plant	2	"
Cry1A (c)	BT Xtra (DBT418)	whole plant	1	"
Cry1A(b)	Knockout (176)	leaves, pollen	2	"

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

Table 6 • Transgenic corn for control of stalk borer.

Bt protein	Tradename (event)	Toxin expression	Reduction in leaf damage[1]	Source
Cry1A(b)	Knockout (176)	leaves, pollen	2	Pilcher et al. 1997

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

Table 7 • Transgenic corn for control of southwestern corn borer.

Bt protein	Tradename (event)	Toxin expression	Reduction in plant damage[1]	Source
Cry9C	Starlink (CBH351)	whole plant	5	Higgins et al. 1999
Cry1A(b)	Knockout (176)	leaves, pollen	3	Higgins et al. 1999
Cry1A(b)	Knockout (176)	leaves, pollen	1	Buschman et al. 1999
Cry1A(b)	YieldGard (Mon810)	whole plant	5	Higgins et al. 1999
Cry1A(b)	YieldGard (Mon810)	whole plant	5	Buschman et al. 1999
Cry1A(b)	YieldGard (Bt11)	whole plant	5	Higgins et al. 1999
Cry1A (b)	YieldGard (Bt11)	whole plant	5	Buschman et al. 1999
Cry1A(b)	YieldGard (Bt11)	whole plant	4	Williams et al. 1997

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

Effect of Bt Corn and Planting Date on Corn Yield in the Southeastern United States

In the southeastern United States, corn earworm and fall armyworm are the major caterpillar pests of corn. Corn is usually planted early (early March in southern Alabama to early April in northern Alabama) to avoid infestation by these insects. This planting schedule limits the options for a cropping rotation. A series of experiments in Alabama, as well as studies from the University of Georgia and the University of Florida, have been conducted to determine when Bt corn would most likely be profitable. Results from Alabama in 1998 illustrate how the expression of the *B. thuringiensis* toxin can provide some protection from fall armyworm and corn earworm infestations, resulting in higher yields. Insect pressure was not particularly high in corn planted during the early planting dates. Bt corn hybrids did not outyield southern-adapted non-Bt corn hybrids in the early planting date (Figure 1). However, in the latest planting date, Bt corn hybrids had a distinct yield advantage. If corn hybrids can be developed that express the Bt toxin throughout the plant and yield well in the summer, farmers in the southeastern United States may be able to adopt alternative cropping systems.

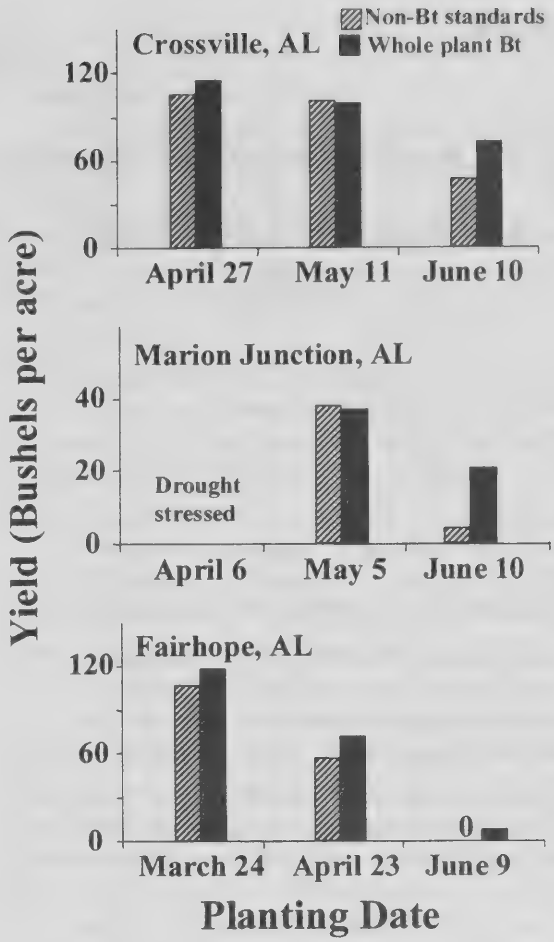

Figure 1 • Effect of Bt corn and planting date on yield of corn infested with fall armyworm and corn earworm, Alabama, 1998.

Table 8 • Transgenic corn for control of sugarcane borer.

Bt protein	Tradename (event)	Toxin expression	Reduction in insects per plant[1]	Source
Cry1A(b)	YieldGard (Mon810)	whole plant	5	Reagan et al. 1999

[1] 1 = 0–20% reduction relative to the control, 2 = 20–50% reduction, 3 = 50–70% control, 4 = 70–90% reduction, and 5 = 90–100% reduction relative to the control.

Table 9 • Transgenic corn for control of Banks grass mite.

Bt protein	Tradename (event)	Toxin expression	Reduction in leaf damage[1]	Source
Cry1A(b)	YieldGard (Mon810)	whole plant	1	Peairs et al. 1999
Cry1A(b)	YieldGard(Bt11)	whole plant	1	—
Cry1A (c)	BT Xtra (DBT418)	whole plant	1	—
Cry1A(b)	Knockout (176)	leaves, pollen	1	—

[1] 1 = 0 20% reduction relative to the control, 2 = 20 50% reduction, 3 = 50 70% control, 4 = 70 90% reduction, and 5 = 90 100% reduction relative to the control.

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Prescriptive Use of Transgenic Hybrids for Corn Rootworms: An Ominous Cloud on the Horizon?

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The race continues to commercialize a transgenic insecticidal cultivar for the control of the corn rootworm complex, *Diabrotica* spp. There is no mystery about why the agribusiness sector is so keen in the development of this new and exciting approach to control corn rootworms. Metcalf (1986b) described rootworms as the billion-dollar complex based upon the costs associated with the purchase of soil insecticides and also due to crop losses caused by larvae and adults. On a national scale, farmers may eventually invest more than $400 million (annually) in transgenic technology fees (assumes a cost of $15 per acre) to prevent corn rootworm larval injury (Michael E. Gray [MEG] estimates). These resources would be invested to prevent an economic loss of $650 million (MEG estimates). Thus, the potential return on the investment for farmers nationally is estimated at roughly $250 million. These figures are based upon the continuing geographical expansion of the new western corn rootworm variant that does not restrict its oviposition to corn. The use of transgenic hybrids for corn rootworm control is expected to mirror or surpass that of soil insecticides, assuming the cost of a technology fee is comparable with that of a soil insecticide. So, a quick look at these numbers reveals the potential for a very large market for transgenic insecticidal cultivars for corn rootworms. The race is well underway, and currently, it remains unclear how close the contestants are to the finish line. Target dates of 2001 or 2002 have been suggested as realistic, at least for limited commercialization attempts.

Resistance Management Considerations for Transgenic Rootworm Hybrids

At the 1999 Crop Protection Technology Conference, I outlined many aspects of corn rootworm biology and ecology that should be considered in the development of resistance management plans for this important complex (Gray 1999). I suggest that the potential for resistance development by corn rootworms is much more acute than for European corn borer, *Ostrinia nubilalis* (Hübner). Reasons for this opinion include knowledge of dispersal characteristics of larvae (Suttle et al. 1967; Short and Luedtke 1970; Strnad et al. 1986; Strnad and Bergman 1987a,b; Gustin and Schumacher 1989; MacDonald and Ellis 1990; Strnad and Dunn 1990) and adults (Ruppel 1975, Witkowski et al. 1975, Coats et al. 1986, Grant and Seevers 1989, Youngman and Day 1993), narrow host range (Branson and Ortman 1967a–c; Branson and Ortman 1970; Branson 1971), injurious nature of two life stages within a single growing season, and a history of resistance development to several insecticides (Ball 1983, Metcalf 1986a, Gray and Luckmann 1994, Meinke et al. 1998). Development of sound resistance management strategies for the deployment of transgenic corn rootworm cultivars is essential to prolong the usefulness of this technology. Even with these strategies in place, in my opinion, resistance will develop eventually. Are there resistance management ideas worthy of consideration for corn rootworms that differ from the approaches currently recommended for European corn borer? I propose that the answer to this question is "yes."

Transgenic Insecticidal Cultivars: Examples of Pest Management Tools?

If a producer elects to purchase a *Bacillus thuringiensis* (Bt) hybrid for European corn borer control, is this an example of a sound pest management approach? Some would argue that it is because the use of a Bt hybrid is nothing more than using host plant resistance to prevent economic loss. After all, host plant resistance is the "cornerstone" of many well-designed IPM programs. Others contend that the purchase of Bt seed for European corn borer control is no better than using a broadcast application of an insecticide with no scouting input or knowledge of spring densities of this pest. The truth lies somewhere in between these viewpoints. It is true that the purchase of transgenic seed to control European corn borer occurs most often in the fall or early winter preceding the upcoming growing season. Entomologists have never had much success in predicting subsequent infestations of European corn borer even when equipped with knowledge of fall densities of this pest. Instead, they often speak in general terms concerning the likelihood of an infestation (Briggs and Guse 1986). For example, based on historical records, producers in northwestern counties of Illinois are more likely to have economic infestations of European corn borer than are farmers south of Interstate 70. But, it is a stretch to say that producers equipped with this knowledge are making informed pest management decisions when they decide to invest in the Bt technology for European corn borer control. Unfortunately, scouting fields and using economic thresholds does not work when it comes to making decisions about the use of a Bt hybrid for European corn borer control. In the real world, after they have reviewed their bottom lines for the season, farmers will continue to make educated guesses about the best seed choices for the upcoming growing season, Bt or non-Bt, being just one aspect of the seed selection process. One thing is for sure, most producers are not asking themselves the philosophical question: "Does the use of a Bt hybrid fall within the framework of an IPM program?" Although issues such as the development of resistance remain a concern of producers (Pilcher and Rice 1998), profitability drives crop production and protection decisions. As mentioned, scouting and the use of economic thresholds do not work well in deciding whether to purchase a Bt hybrid for European corn borer control. However, this is *not* true for corn rootworms, and future management decisions that hinge upon whether to use a transgenic insecticidal cultivar for this pest complex may indeed rely upon the fundamental components of IPM, scouting, and economic thresholds.

Frequency of Corn Rootworm Infestations within Farmers' Fields

How frequently do farmers face economic infestations of corn rootworm larvae within their fields? Bigger and Petty (1965) conducted surveys (1954–1963) of 452 producers' fields (untreated strips) in Illinois and found that 28% (range for the 10 years, 12–43%) of the fields were infested with northern corn rootworm. The average percentage of plants infested was 18% (range for the 10 years, 11–27%). These figures are good estimates of the percentage of fields infested only with northern corn rootworm. Western corn rootworm was detected for the first time in Illinois during 1964. Research conducted in Iowa led Turpin et al. (1972) to predict that 36% of continuous (nonrotated) cornfields in Iowa exceeded the economic injury index of 2.5 (Hills and Peters 1971). They offered the following admonition concerning soil insecticide use and corn rootworm injury: "Iowa in 1969 had 10 million corn acres, of which ½ (5 million acres) followed a corn crop in 1968. Farmers used insecticides on 72% of the corn-following-corn acres in 1969. Since the prediction equation showed a need for insecticides on 36% of the corn-following-corn acres, the other 36%, or 1.8 million acres, of Iowa corn ground was treated needlessly for rootworm control." Research conducted (1972–1974) in the eastern Corn Belt by Turpin and Thieme (1978) revealed that corn rootworm larvae occurred in 34% of 234 Indiana cornfields. Average root ratings in producers' control strips (no soil insecticide used) exceeded a root rating of 2.5 (Hills and Peters 1971) in only 3.4% of the fields. By conducting a series of on-farm experiments in Illinois during 1990 and 1991, Gray et al. (1993) determined that 26 of 58 producers' fields (45%) had root injury at or above an average root rating of 3.0, the so-called economic injury index. In the Illinois study, only 7 of 58 producers' fields (12%) had root injury equal to an average root rating of ≥4.0 in untreated areas of their fields. Root ratings of ≥4.0 typically predispose a plant to lodging and subsequent yield loss. These data confirm that Illinois' producers use soil insecticides on more continuous corn acres than necessary for corn rootworm control. Yet in the early 1990s, a large percentage of continuous corn acres in Illinois (2.5 million acres, 88% of continuous corn in Illinois) was

being treated with soil insecticides each spring (Pike and Gray 1992).

Results from more recent studies conducted in eastern states also suggest that many cornfields do not support economic infestations of corn rootworm larvae. Davis and Coleman (1997) found that only 30 and 50% of New York cornfields exceeded a gain threshold of 6.4 bu/acre in 1993 and 1994, respectively, at a soil insecticide cost of $16/acre and grain valued at $2.50/bu. Kuhar et al. (1997) conducted field investigations (1993 and 1994) in 32 continuous cornfields in Virginia. They determined that only 28% of the fields had root injury that exceeded a rating of 3.5 in control strips (no soil insecticide used); only 19% of the cornfields had economic losses due to rootworm injury. They concluded that much of the soil insecticide used is unnecessary on the continuous corn acres within Virginia.

I propose that the take-home message of these papers is the following: Research to date indicates very clearly that the investment in a transgenic insecticidal cultivar for corn rootworm control will not pay dividends on all planted corn acres. Economic infestations of corn rootworm larvae do not occur in most cornfields. This knowledge supports the use of established scouting techniques for adult corn rootworms in late summer and the use of transgenic hybrids for corn rootworms the subsequent spring in only those fields that exceeded economic thresholds.

Predicting Economic Infestations of Corn Rootworms: A Precise Science?

Adult corn rootworm management programs have been recommended and practiced in many states for more than 2 decades. The use of broadcast insecticide applications to suppress oviposition by corn rootworm females is much more common in the western Corn Belt, especially in Nebraska. Although adult control programs are not as common in the eastern Corn Belt, Gray and Steffey (1999) offered the following recommendation regarding this rootworm management approach: "Another alternative is controlling rootworm adults in corn to prevent them from laying eggs. If the number of beetles reaches or exceeds 0.75 per plant, apply an insecticide when 10 percent of the females are gravid (with eggs). Continue to monitor fields weekly after treatment for rootworm beetles. A second application of an insecticide may be necessary if the number of beetles reaches or exceeds 0.5 per plant . . . Scout for rootworm beetles from mid-July through early September 1999 to determine the potential for rootworm larval damage in 2000."

Economic thresholds used for beetle management programs should reflect whether a field has just been rotated recently or has been devoted to corn production for many years. Godfrey and Turpin (1983) determined that first-year cornfields (rotated cornfields) had greater percentages of female western corn rootworm adults with greater ovarian development than adults found in continuous cornfields after July 30. They suggested that economic thresholds for adults in first-year cornfields should be 50% less than thresholds used in continuous cornfields. Weiss and Mayo (1985) recommended that beetle counts should be adjusted according to the plant population within a field. By doing so, they concluded that more accurate estimates of adult densities and, more importantly, potential oviposition could be made. Naranjo and Sawyer (1989) discovered that the oviposition per female was not as great in earlier-planted and earlier-flowering fields and suggested that thresholds should be adjusted upward for early-planted fields compared with late-planted fields. Riedell et al. (1992) indicated that irrigation reduced losses caused by corn rootworm larvae when plants were exposed to hot and dry weather. Maize grown under irrigated conditions suffered less yield loss under equal levels of rootworm larval injury compared with dryland maize. They suggested that economic injury levels and thresholds should be adjusted accordingly for irrigated production systems. This review of the literature suggests clearly that entomologists have considerable knowledge about how economic thresholds for corn rootworms should be adjusted according to a variety of crop-production parameters.

For decades, entomologists at land-grant institutions have recommended that producers scout their fields for corn rootworm adults so that decisions can be made to suppress oviposition or, in some instances, to make more responsible choices regarding the use of a soil insecticide the following spring. In deciding whether to use a soil insecticide, Gray and Steffey (1999) recommended the following thresholds: "Alternate corn with another crop when possible, particularly in fields where rootworm beetles averaged 0.75 or more per plant, or if the soil insecticide did not adequately protect the roots in 1998. If you intend to grow corn after corn and if rootworm beetles averaged 0.75 or more per plant in corn after corn or 0.5 per plant in first-year corn last summer, apply a rootworm soil insecticide at planting time."

Among entomologists, some disagreement remains regarding the reliability of these recommendations to identify accurately those fields that do not require an application of a soil insecticide at planting. Stamm et al. (1985) evaluated the utility of an adult threshold for western corn rootworm in making larval control recommendations to Nebraska producers. In all, 74 fields were used during their 3-year experiment. Cornfields with beetle densities of less than one beetle per plant each week throughout August were considered unlikely candidates for economic larval injury the following year and soil insecticides were not recommended. If adult densities exceeded one beetle per plant in August, farmers were advised to use a soil insecticide at planting the following spring. Stamm et al. (1985) reported that this pest management approach was reliable >80% of the time. If the economic threshold was reduced to 0.75 beetle per plant, the predictive reliability increased to 90%. A root-injury index of 2.75 (Hills and Peters 1971) was considered as the economic injury index for this research endeavor. During this study, the percentage of fields treated with soil insecticides declined from 90 to 28%, suggesting that scouting for adult corn rootworms and using an economic threshold can be a viable pest management approach for corn rootworms.

Is scouting and the use of thresholds really that simple for corn rootworms? The answer is "no." The findings of Foster et al. (1986) are in direct contrast to those reported by Stamm et al. (1985). Densities of adult corn rootworms were determined in each of 3 years (1979–1981) in 31, 43, and 44 Iowa cornfields, respectively. These researchers found that adult economic thresholds failed to accurately predict economic larval damage in >50% of the fields. At the conclusion of their research, they offered the following controversial statement "The optimal strategy for managing corn rootworms in Iowa in our study was not to sample for adults and always to treat corn following corn with a soil insecticide at planting time." They maintained that the current sampling procedures and adult thresholds were not useful in deciding when no insecticide treatments were needed.

So, can economic infestations of corn rootworm larvae be predicted accurately? Are sampling and the use of economic thresholds for corn rootworms an art or a science? Honestly, it depends on the research that you cite. However, what are the consequences of repeatedly erring on the side of treating for corn rootworms when economic infestations do not exist? And, as mentioned previously, in most cornfields, larval densities are below the economic injury level.

Corn Rootworms and Insecticide Resistance: Here We Go Again

Adult corn rootworm management practices have been recommended by consultants in Nebraska for decades and have been subscribed to by many producers as an alternative to soil insecticides. Unfortunately, the broadcast adulticides were usually the sole management tactic used by many farmers. Meinke et al. (1998) confirmed that western corn rootworm has developed resistance to methyl parathion (16.4-fold) and carbaryl (9.4-fold) in areas of Nebraska where applications of these products have been common for years. The F1 generation also displayed resistance characteristics, confirming the heritability of this trait. Excessive use of broadcast chlorinated hydrocarbon insecticides (aldrin, heptachlor) for corn rootworm control from the late 1940s through the early 1960s resulted in the development of resistance (Ball and Weekman 1963). The resistant western corn rootworm strain spread rapidly, and by 1980, corn production across much of the Corn Belt was affected (Metcalf 1986a). Because of the failure of crop rotation as a viable corn rootworm management approach in an increasing area of the eastern Corn Belt, the spread of an organophosphate-resistant strain of western corn rootworm would pose a significant corn production challenge to producers. Corn rootworms have shown repeatedly that they are superbly capable of adapting to a variety of insecticides and even to a cultural practice. Any notion that they will not develop resistance to transgenic insecticidal cultivars at some point is foolhardy.

Prescriptive Use of Transgenic Insecticidal Cultivars for Corn Rootworms

Unlike the use of transgenic insecticidal cultivars for European corn borer management, the use of transgenic hybrids for corn rootworms could work in concert with existing scouting programs and established economic thresholds. By monitoring their fields for corn rootworm adults in late summer, farmers could base their decision to use transgenic rootworm hybrids the following spring upon scouting input and knowledge of thresholds. Crop consultants

and other professionals in the agribusiness sector could take a very active role in this decision-making process.

Should the use of a transgenic insecticidal cultivar for corn rootworms be legally tied to documentation that indicates that the field in question has been scouted and an economic threshold for corn rootworm adults has been exceeded? Recall that nearly half of the continuous cornfields do not have economic infestations of corn rootworm larvae. Thus, if transgenic cultivars were planted on only half of these fields, in effect, we have created a large refuge across the landscape. Arguably, this refuge would reduce the selection pressure for resistance development. If prescriptive use of transgenic hybrids for corn rootworm control is mandated, should the same argument be made for soil insecticides?

To date, the planting-time use of soil insecticides (banded applications) has not resulted in the development of resistance. Nor is resistance to these products anticipated. Why? In a 3-year study, Gray et al. (1992) reported that greater western corn rootworm emergence occurred in insecticide-treated (carbofuran, chlorpyrifos, and terbufos) areas compared with control plots (no soil insecticide used) in some years. Although soil insecticides usually offer adequate root protection, they are not population-management tools; that is, they do not suppress densities of corn rootworms across the agricultural landscape. Despite this feature that may be perceived as a disadvantage, banded applications of soil insecticides have played the role of a resistance-management tool very well for decades. Because not all corn rootworm larvae are exposed to soil insecticides, in-field refuges have been created unwittingly by farmers each spring. Unlike soil insecticides, transgenic insecticidal cultivars probably will be powerful population-suppression tools, placing enormous selection pressure on the corn rootworm population. Important differences exist between soil insecticides and transgenic hybrids, from a resistance-management perspective, and on this basis, a prescriptive approach for transgenic cultivars seems more justified for transgenic cultivars. To be consistent with this line of reasoning, an argument for the prescriptive use of broadcast adulticides for corn rootworm control also can be made.

If we accept that the genes used within a transgenic cultivar for corn rootworms are a natural resource (belonging to no one) and, therefore, should be preserved, a philosophical debate ensues. Synthetic insecticides that are used to control insects are, by definition, synthesized, and although their loss due to resistance development by an insect population is regrettable, it pales in comparison to the loss of a natural resource squandered through misuse within a pest management program. From my vantage point, the stakes are greater when it comes to preserving the long-term integrity of transgenic cultivars for corn rootworm control compared with insecticides. If this argument is accepted, a prescriptive approach for the use of transgenic cultivars for corn rootworm control is worthy of broad consideration by the scientific and regulatory community.

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Global Climate Change: What Will It Mean For Illinois?

KENNETH E. KUNKEL

The issue of global climate change is one of the most important environmental issues facing society. There is serious and legitimate concern that human activities may cause major irreversible changes to our climate. It is uncertain how the climate of Illinois will change. Nevertheless, this uncertainty does not diminish the fact that there could be serious consequences for our state and for the nation.

Scientific Basis of Global Climate Change

There is considerable scientific debate about the extent to which the earth's climate will change in the near future. However, there is a consensus that human activities have the potential to cause major climate change. This consensus is based on two widely accepted characteristics of the atmosphere. First, human activities have caused sizable increases in atmospheric concentrations of certain gases called greenhouse gases. The most significant of these gases are carbon dioxide, chlorofluorocarbons, methane, and oxides of nitrogen. Measurements have confirmed that the atmospheric concentrations of these gases have increased, primarily due to human activities. The most important of these gases is carbon dioxide. Concentrations of carbon dioxide have increased >25% since the beginning of the industrial revolution, caused mostly by the burning of fossil fuels (coal, oil, natural gas).

Second, greenhouse gases absorb infrared radiation; thus, they trap energy emitted by the earth rather than allowing this energy to escape into space. This effect, called the greenhouse effect, helps to keep the earth habitable. Without the greenhouse effect, the earth's temperature would be considerably colder and much of the earth's surface would be frozen. The present concern is that increasing the concentrations of the greenhouse gases will amplify this effect and cause rapid and disruptive warming.

Computer Projections of the Future

To address this issue, atmospheric scientists have constructed computer models of the earth's atmosphere and surface. These computer models simulate atmospheric circulation patterns and investigate what could happen to these patterns with increases in greenhouse gas concentrations. These models are the best tools available to examine the effects of greenhouse gas increases on our climate system. However, they are very computationally intensive and, even with the fastest supercomputers, simplification of the models is necessary. The models are not yet capable of replicating every important natural process. Thus, the results of model experiments are interesting and informative, but there is significant uncertainty about what they can actually predict.

Many scientific groups have constructed such models and conducted computer simulations of the future climate. All of the models predict a rise in global temperatures during the 21st century. One source of debate is that these models differ considerably in the rate of warming. The global projected temperature increases are in the range of 2 to 7°F by the end of the 21st century (IPCC 1996). All of these models also show an increase in average global rainfall, but the amount of increase varies among the models.

These models also vary in their predictions about what may happen on a regional scale. For example, there is a substantial range in their predictions for Illinois. Some models suggest much warmer and drier conditions, with summers similar to those of the Dust Bowl era of the 1930s. Others predict less warming and more rainfall. For temperature, the range of model predictions of warming for Illinois is 0.5–1.4°F by 2020, 1.4–3.2°F by 2050, and 2.3–7.2°F by 2100 (Wigley 1999). These increases may not seem substantial because we often experience day-to-day temperature variations that are much larger. However, our mean annual temperature is actually very stable and the projected temperature increases by 2100 would exceed any temperatures in the historical record. These models are not yet sophisticated enough to predict what may happen to specific conditions that have great impact on Illinois, such as the occurrence of severe thunderstorms. The differences among models and the lack of information on certain important climate conditions limit what can be predicted about the future climate. However, we can make educated guesses about what may happen if the models are correct in predicting warmer conditions in the 21st century by examining what has happened during past hot periods.

Future Scenarios Based on Historical Experience

Temperature and precipitation information has been collected by volunteer observers of the National Weather Service at various Illinois locations since the late 19th century. Forty-one of these locations were selected for analysis because they have nearly complete records dating back to 1900. For each station, summer (June, July, August) and winter (December, January, February) temperatures were calculated for each year. The summers and winters with above-average temperatures were selected for further analysis. Various climatic conditions were examined to see whether they were related to the magnitude of above-average temperatures. The following examples show conditions that were strongly related to the seasonal temperature.

Figure 1 shows how the number of days with temperatures exceeding 95°F is related to the mean summer temperature. This figure also shows an expected result: the number of very hot days increases significantly as mean summer temperatures increase. For example, for summer temperatures of 5 to 6°F

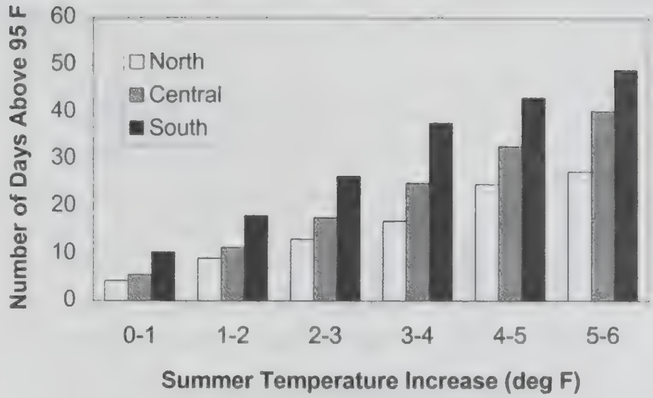

Figure 1 • The number of days >95°F during June, July, and August as a function of the mean summer temperature expressed as a deviation from normal. Average values were calculated separately for northern, central, and southern Illinois.

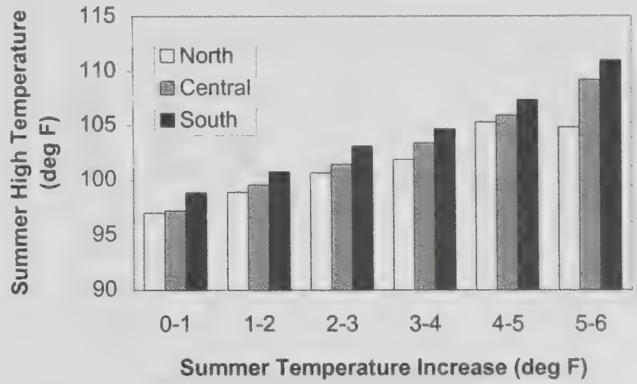

Figure 2 • The maximum temperature of the hottest day in the summer (June, July, and August) as a function of the mean summer temperature expressed as a deviation from normal. Average values were calculated separately for northern, central, and southern Illinois.

above the present normal, the number of days with a temperature >95°F ranges from approximately 25 in the north to near 50 in the south. Thus, we could experience more crop-damaging extreme high temperatures in future summers if warming occurs. Figure 2 shows how the temperature of the hottest day of the summer changes with mean summer temperature. During an average summer, the hottest day is typically in the upper 90s to near 100°F. However, during past summers that were 5 to 6°F above normal, the hottest summer temperature was approximately 105°F in the north and 110°F in the south.

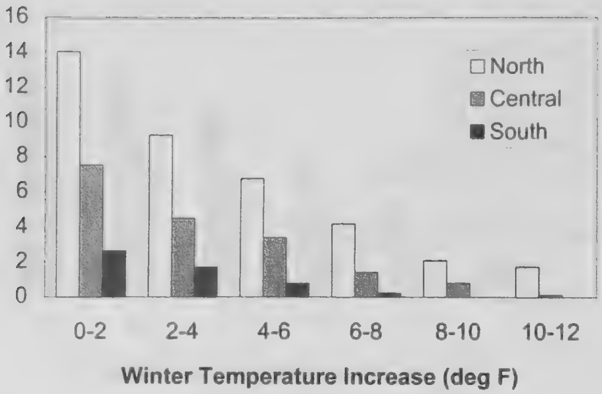

Figure 3 • The number of days <0°F during December, January, and February as a function of the mean winter temperature expressed as a deviation from normal. Average values were calculated separately for northern, central, and southern Illinois.

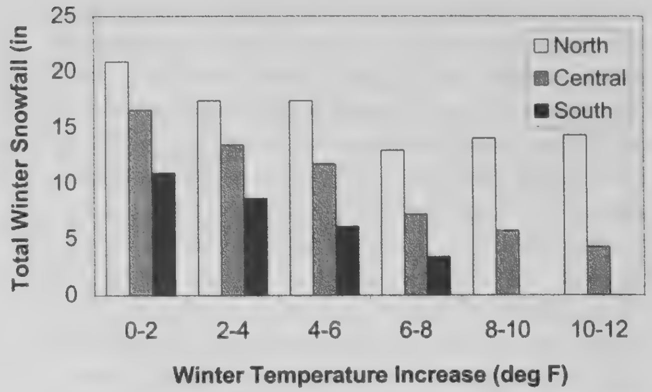

Figure 5 • The average total snowfall for December, January, and February as a function of the mean temperature of the winter expressed as a deviation from normal. Average values were calculated separately for northern Illinois (open), central Illinois (gray), and southern Illinois (dark).

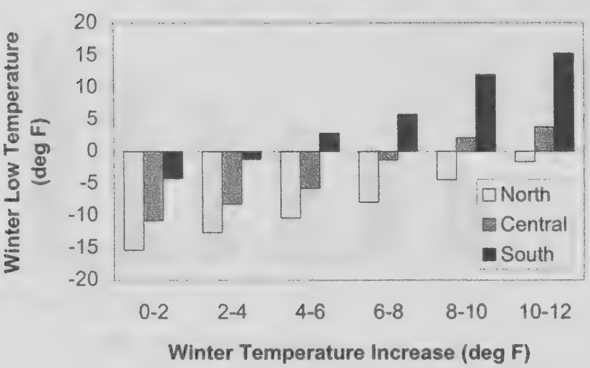

Figure 4 • The minimum temperature of the coldest day in the winter (December, January, and February) as a function of the mean winter temperature expressed as a deviation from normal. Average values were calculated separately for northern, central, and southern Illinois.

Figures 3–5 show results for past winters. Figure 3 shows the relationship of the number of days with temperatures <0°F as a function of the mean winter temperature. Winter temperatures are more variable from year to year and some winters have been as much as 10 to 12°F above the mean, a much larger deviation than the very warmest summers, which have been only 5 to 6°F above normal. Figure 3 shows that the number of very cold days decreases as mean winter temperature increases, an expected result. For example, for mean winter temperatures of 8°F above normal, the number of days <0°F ranges from only two in the north to none in the south. Figure 4 shows how the low temperature of the coldest winter day is related to the mean temperature of the winter. As expected, the lowest temperature increases as the mean winter temperature increases. For mean winter temperatures of 8°F above normal, the coldest temperature of the winter ranges from just a few degrees <0°F in the north to 10 to 15°F above zero in the south. Figure 5 shows the total snowfall for December, January, and February as a function of the mean winter temperature. In the southern and central counties, the total snowfall decreases significantly as the winter temperature increases. For example, past winters of 8°F above normal have been characterized by little or no snow in the south and by approximately 5 in. in the central region. Interestingly, in the northern counties, there is only a very modest decrease in snowfall as mean winter temperature increases. This decrease seems to be a result of the colder temperatures in the north. Even during warm winters, the temperature is still usually below freezing and cold enough for precipitation to fall as snow rather than rain.

Conclusions

The above-mentioned examples illustrate some plausible changes in the future climate of Illinois, based on what has happened in the past during warm periods. The implications of a permanent change to much warmer conditions are uncertain. As one

example of a possible impact, warmer temperatures could result in the northward migration of pests (Sutherst et al. 1995). Current models suggest that there may be little overall change in U.S. agricultural production, but there may be regional winners and losers (Adams et al. 1999). Northern growing regions may benefit from warmer temperatures and a longer growing season. However, southern regions and parts of the Corn Belt could experience yield reductions because of increased temperature and soil moisture stress. Long-term management of agricultural systems should consider the potential for substantial climate changes.

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Using Illinois' Digital Imaging System to Diagnose Your Plant and Pest Problems

DENNIS BOWMAN

The Situation

Technology has made it possible for University of Illinois Extension staff to serve our clientele better. E-mail, the Internet, desktop publishing, and other technological advances have enhanced our ability to serve our clientele and respond quickly to their needs. But until recently, this technology had not been applied to valued services such as the diagnosis and identification of plant and pest problems.

When extension clientele have a plant problem, they often turn to University of Illinois Extension staff for assistance. When pests and problems cannot be diagnosed locally, samples are often sent to the University of Illinois Plant Clinic. Samples reach the Plant Clinic through a variety of paths. Clientele may call campus specialists directly. A quick diagnosis may be made over the telephone. Often, however, the problem may be too difficult or the caller's descriptive skills may be insufficient for a specialist to be able to reach a confident and accurate diagnosis. Clientele also may contact extension field staff to assist with a problem diagnosis. Even trained staff may run into unusual or complex problems that require a second opinion or additional expertise.

The solution to both of these situations has been to send a sample to the Plant Clinic. A representative sample must be collected, appropriately packed, and mailed to campus. Unfortunately, when it gets to campus, it often is difficult to analyze. Even if it arrives quickly and in good condition, it may be a couple of days before the appropriate specialist can get out to the laboratory to make a diagnosis. Then a response must be drafted and sent back to the client. A 10-day response time is normal during the growing season.

Extension clientele appreciate the service and accept the delay, but new technology will allow extension specialists, field staff, and Plant Clinic staff to speed up the pace of this process significantly. Both extension staff and clients have discovered the powerful combination of e-mail and digital cameras. The University of Georgia developed a system that uses digital imaging devices distributed across the state to take digital pictures of a problem and send them almost immediately to specialists via the Internet.

The University of Georgia Distance Diagnostics Project

The Distance Diagnostics through Digital Imaging system at the University of Georgia College of Agricultural and Environmental Sciences allows textural information and descriptive images to be submitted directly from Georgia county extension offices for rapid diagnosis by resource professionals at the University. The system uses conventional software and hardware, which have proven to be effective and reliable. Using such programs and equipment saved much development time. Taking advantage of the Internet and the World Wide Web for submission of information and images vastly improves the convenience of accessing such material as needed by various individuals.

Extension organizations in other states are developing pilot projects based on Georgia's Distance Diagnostics through Digital Imaging.

The University of Illinois Extension Pilot Project

At the University of Illinois, the Department of Crop Sciences, the Office of Information Technology and Communication Services, and Extension created a pilot project to adapt the University of Georgia project to Illinois situations. The goals of the pilot project were to test the concept of distance diagnostics, test the Web-based management system, and determine the appropriate level of equipment needed.

For the concept to be effective, it needed to work in a variety of situations. Extension field offices across the state vary greatly in numbers and skill levels of staff. There is no longer a trained extension agricultural professional in every county. Some satellite offices have only a secretary for most of the week, whereas some unit offices have both trained agricultural and horticultural staff members. For the pilot project, 12 extension units reflecting this range of conditions were included. Extension educators in integrated pest management, crop systems, and horticulture agreed to provide the diagnoses.

The University of Georgia assisted in developing the Web-based sample submission and management system by customizing their system to meet Illinois needs. When a sample was brought into an extension field office, the staff collected background information about the sample, similar to the data sheet that accompanies samples to the Plant Clinic. Images of the plant or pest were taken with the available equipment. The staff then accessed the University of Illinois Distance Diagnostics Web site and opened an on-line submission form. The sample background information was filled in, and the images were attached to the form. When the staff clicked on the "Submit Form" button, the system generated an e-mail message to an extension educator. The system selected the appropriate educator based on the county from which the sample was sent and on the type of expertise (crop, weed, disease, insect, or horticulture) needed. The sample originator also was notified about the sample number assigned to his or her sample and the name of the designated diagnostician. The e-mail notice that the diagnostician received contained a "hot-link" that gave immediate access to the sample. The educator could make his or her diagnosis on-line or forward the sample to another diagnostician, if needed. When the diagnosis was made, an e-mail message was sent to the originator; the message contained the diagnosis, recommended treatment, if needed, and information about how to contact the diagnostician. A notice was generated automatically if a sample remained undiagnosed after 3 days.

The comprehensive suite of equipment used in the Georgia program cost approximately $10,000 per site. This suite included a new computer, color printer, compound microscope, dissecting microscope, digital video camera, video capture card, hand-held digital camera, and accessories. Those of us involved in the Illinois project decided to look at a variety of equipment. All extension field offices had already been issued a digital camera, new computers, and color printers. Of the 12 extension unit offices participating in the pilot project, half received a dissecting microscope equipped with a digital video camera wired into a computer. The other group used a hand-held camera. Both groups attended a 2-day training session. Additionally, regional centers and one unit received compound microscopes.

The training was conducted in early July, and the system became operational in late July. As of October 21, 1999, the system had posted 491 samples. This number includes samples posted during the testing and training phases of the pilot project.

Evaluation

An evaluation of the pilot project was conducted in October. Examination of the database showed that 20% of the samples were diagnosed the same day that they were submitted, and another 25% were diagnosed by the next day. Part of the evaluation was a participant survey. There was unanimous agreement that the project should be continued and expanded. The project will be expanded for the 2000 growing season. The specific expansion plans currently are under review.

Chemical Control of Wheat Scab – Problems and Progress

MARCIA MCMULLEN

Recent scab (Fusarium head blight) epidemics in wheat in the United States have caused enormous yield and quality losses in both spring and winter regions (McMullen et al. 1997). The severity and reoccurrence of this disease in major wheat-growing states have been threats to wheat acreage and to the wheat industry. Control of this disease has been difficult because of the complex nature of the host–pathogen–environment interaction. Host resistance looks promising (Bai and Shaner 1994, Stack 1999), but full resistance in adapted cultivars is still a future goal, especially in certain winter and durum wheats. For now, growers need immediate solutions for preventing this disease from causing economic losses.

Chemical control would be a promising immediate solution, if effective and affordable products were available. Until recently, evaluations of fungicides for control of wheat scab were done primarily in Europe (Mauler-Machnik and Zahn 1994, Mesterhazy and Bartok 1996). Results in Europe indicated substantial control of this disease with a variety of products, many of which were not registered in the United States, or were not registered for full heading or flowering application, the time of infection of wheat by the scab fungus. Initial work in the United States gave limited or variable results. Jacobsen (1977) used standard foliar application methods in his tests in Illinois and applied fungicides to wheat at 50% heading and 10 days later, or at milky dough stage of kernel development. A benomyl + mancozeb mix significantly reduced scab and improved yield by 15–20% in Jacobsen's trials. Milus and Parsons (1994) used standard foliar disease control techniques to apply several different fungicides, and applied them at 50% heading in Arkansas. In his studies, fungicides did not significantly reduce scab or increase yield.

The severity of the scab epidemics in the United States in 1993, 1996, and 1997 necessitated a new look at finding safe fungicides and methods of application that would improve chemical control. Traditional products and methods were not providing adequate results under severe epidemic conditions. This article describes several of the main problems in achieving success with chemical control, and some of the collaborative efforts that have led to progress in this area.

Problems

Product Availability

For most of the 1990s in the United States, registered wheat fungicides effective against scab (Fusarium head blight) were few and far between. Only two effective products were registered for heading application, benomyl (Benlate) and mancozeb (Dithane, Penncozeb, Manzate). Benomyl fungicide is a locally systemic product with good activity against Fusarium, but with less activity against the leaf spot and rust fungi that also plague wheat. Benomyl is labeled for application to wheat up to 21 days before harvest. The mancozeb fungicides are protectant fungicides, not systemic, and they must be applied several times to wheat to persist long enough for adequate disease control. The mancozebs have good activity against leaf rust and leaf spot fungi, but less activity against *Fusarium* species than benomyl. The mancozebs are labeled for application to wheat up to 26 days before

harvest, which also generally allows application through flowering. Jacobsen's (1977) study indicated that a combination of benomyl at 0.5 lb/acre and mancozeb at 1 lb/acre applied before or after flowering would give adequate protection against scab, but it was not consistent in performance and did not control leaf diseases adequately. In our work in North Dakota, we found that the wettable powder formulations of these products often subjected workers to fungicide exposure and plugged sprayer nozzles if not adequately agitated in the sprayer tank. The cost of the combination for one application was generally high for wheat, approximately $12/acre. Propiconazole (Tilt) also was registered for wheat, a locally systemic product with a wide spectrum of activity, but it was registered only for application through early flag leaf emergence, a timing too soon for control of scab. The following characteristics of a fungicide for control of scab were needed: registered for heading application, effective, economic, safe, systemic, easy to mix, and wide-spectrum activity against scab and other important fungal wheat diseases.

Application Methods

Another problem with chemical control of wheat scab was that application methods used to control leaf diseases were being used to control head scab. The *Fusarium* fungus infects the wheat head at flowering and continues to develop in the grain through soft dough stage. Fungicides must reach the target site of infection – the flowers and other grain head parts. Systemic fungicides, such as benomyl, are only locally systemic; they do not move upward from the leaf into the head. Thus, application to foliar parts of the wheat plant does not result in head scab control.

Traditional methods of application of fungicides to wheat were designed to control leaf diseases by covering the flag leaf, which is generally flat or horizontal to the spray pattern. Benomyl and mancozebs were generally applied with a spreader or sticker in fairly large droplet sizes to reach the leaf target. The grain head presented a much different and more difficult target. It is vertical to the spray pattern; awns or beards may be present in many cultivars that capture the spray before it reaches the site of infection; and it is glabrous or waxy, unlike the hairy leaves, and does not readily absorb the spray. Studies of various application methods were needed to determine if adaptations could be found that would increase fungicide coverage on the wheat head, and hence improve scab control.

Progress

Cooperative Fungicide Trials

In response to the recent major scab epidemics in the United States, cooperative fungicide trials were established across many wheat classes and environments. Following the 1993 epidemic in the spring wheat regions of North Dakota, Minnesota, and South Dakota, several trials were established to evaluate fungicide efficacy against scab. Preliminary results with the registered products indicated disease control was best achieved if fungicides were applied to flowering wheat, not prior to or after flowering. Benlate at 0.5 lb/acre and mancozeb at 1 lb/acre were standard registered treatments, with 50% reduction in scab severity commonly achieved. In a year when scab was severe, however, a 50% level of control generally was still too damaging to yield and quality. Fungicide work in North Dakota in 1997 indicated that several nonregistered products reduced scab levels by >50%. Results from research studies led to some new registrations of products for 1998.

A Section 18 Emergency Exemption for Folicur (tebuconazole) for heading application was granted by the Environmental Protection Agency to several states in 1998 and again in 1999. Many Special Local Need state labels (Section 24C) were granted for Tilt (propiconazole) for use at heading time on wheat in 1998 and again in 1999. The availability of these two systemic products gave wheat growers additional flexibility in applying fungicides to control scab. The products cost approximately $9.00/acre, were easy to mix, did not plug nozzles, and lowered applicator exposure. In 1999, a federal registration was granted to Quadris (azoxystrobin) for application to wheat up to 45 days prior to harvest.

Uniform Trials

Much of the progress made in getting additional fungicides available for scab control was made possible through cooperative efforts across states to establish uniform fungicide trials. In 1998, plant pathologists in seven states (Indiana, Kentucky, Minnesota, Missouri, North Dakota, Ohio, and South Dakota) participated in uniform fungicide trials that tested five fungicides or fungicide combinations against wheat scab. In the three states with the most severe scab, the average reduction in severity of scab ranged from approximately 30 to 50%, and yield increases averaged up to 16%, but higher levels of control (up to 73%) and higher yields (up to 45%) were achieved in some

Product	Rate	Growth Stage Application
Folicur	6 fl oz	Feekes 10.51
Benlate + Manczb	0.5 lb + 1 lb	Feekes 10.51
Penncozeb	1 lb	Feekes 10.3 + 10.51
BAS 500	0.25 lb AI	Feekes 10.3
BAS 500	0.25 lb AI	Feekes 10.51
Stratego	10 fl oz	Feekes 10.51
Stratego	14 fl oz	Feekes 10.51
Quadris	0.2 lb AI	Feekes 10.51
Quadris	0.15 lb AI	Feekes 10.51

Figure 1 • Treatments in 1999 uniform fungicide trials for evaluating wheat scab control.

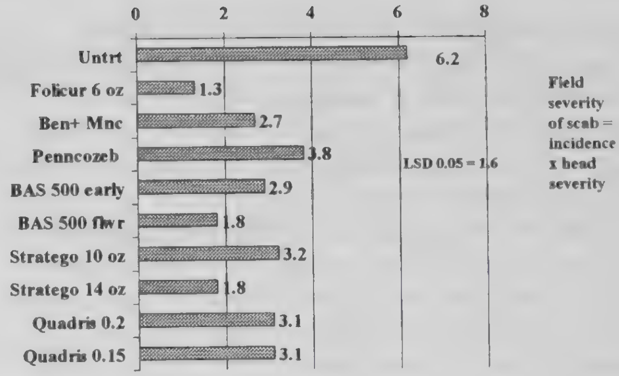

Figure 2 • Percentage of wheat scab severity – three North Dakota and one Illinois uniform fungicide trial combined, 1999.

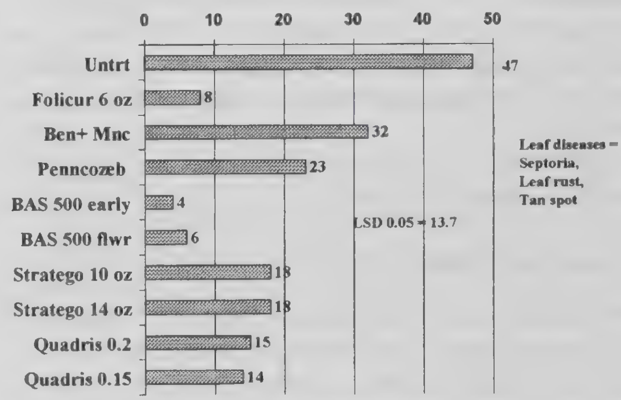

Figure 3 • Percentage of flag disease – three North Dakota and one Illinois uniform fungicide trial combined, 1999.

trials. Levels of vomitoxin (DON) also were reduced from 28 to 56%, and leaf diseases across all seven states were reduced by 37 to 69% (benomyl + mancozeb had least reduction in leaf disease). In 1999, the uniform fungicide trial was expanded to 14 states (Arkansas, Illinois, Indiana, Kentucky, Maryland, Michigan, Minnesota, Missouri, North Carolina, North Dakota, New York, Ohio, South Dakota, and Virginia) and to nine treatments (Figure 1). Some states in 1999, such as Ohio, New York, and North Carolina, had no wheat scab because of severe drought, but North Dakota had moderate levels and Dr. Wayne Pedersen had low, but detectable, levels in his trials in Illinois. In three trials in North Dakota and one in Illinois, scab severity was reduced up to 80% by some flowering time treatments and significantly by most of these treatments (Figure 2). A combination of leaf rust and Septoria leaf spot also was dramatically reduced with the same treatments (Figure 3). Yield responses with the best treatments ranged from 18 to 23%. The best treatments over the four trials in the 1999 studies are not yet registered for wheat, although a request for a special exemption for use of Folicur will again be made in 2000. In Illinois, the Quadris treatment did not reduce the scab severity as well as most treatments, but did result in the highest yield in the trial when applied at a rate of 0.2 lb (AI)/acre (= 12.3 oz/acre). Additional cooperative fungicide trials across states and wheat classes will be conducted in 2000. In addition to fungicides being evaluated for scab control, several scientific teams are looking at biological control across the United States.

Application Techniques

Progress also has been made on application techniques to improve coverage of wheat heads and increase disease control. Preliminary tests in North Dakota indicated that the use of flat fan nozzles with medium droplet sizes (XR8002) directed straight downward from the spray boom were not delivering much of the spray to the head, but instead to the leaves or ground (Hofman et al. 1998). Initial spray studies were established with nozzles that directed the spray at an angle toward the grain head and that provided a smaller droplet size (Figure 4). Spray coverage has been increased dramatically with this angled technique with various nozzles, including an angled, air assist (Spray Air™) nozzle (Figure 5). Disease control has been improved proportionately. Field and green-

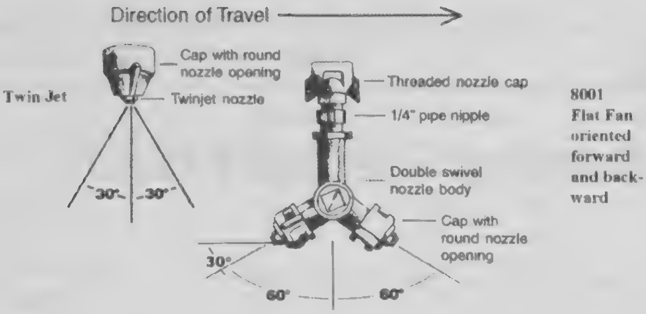

Figure 4 • Application nozzles tested by North Dakota State University for control of wheat head scab.

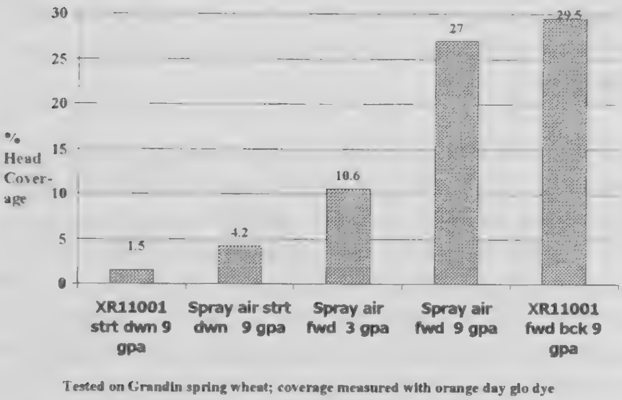

Figure 5 • Relative wheat head coverage with various spray nozzle configurations, Langdon, North Dakota, 1999.

house studies also have indicated that increased water volume generally increases spray coverage and disease control. Studies with aerial application of fungicides indicated that improved results are achieved with application in early morning or late evening, when dew is present to provide additional water for better distribution of the fungicide across the wheat head. Further studies with aerial application are planned for 2000.

Summary

All of the efforts in studying fungicides for scab control and in improving methods of delivery are producing positive results. New products with increased flexibility of application timing are now available, either through special registrations or full registrations. Additional products are being tested and seem very promising. Studies with various application techniques have demonstrated ways to improve head coverage and disease control, without sacrificing leaf disease control. These results give wheat growers more opportunities for combating wheat scab and provide applicators with opportunities for economically modifying their equipment for improved control.

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Soybean Sudden Death Syndrome – What's Next?

GLEN L. HARTMAN AND WAYNE L. PEDERSEN

Sudden death syndrome (SDS) was first observed in Arkansas in 1971, other states in the south in 1984, and in Illinois and Indiana in 1985. Yield losses from SDS range from slight to nearly 100% and are dependent on disease onset and severity. Infected plants often have increased flower and pod abortion and reduced seed size. Symptoms first appear on leaves as scattered, interveinal chlorotic spots that often coalesce, leaving only the midvein and major lateral veins green. Severely affected leaflets detach from the petioles. Severe foliar symptoms give affected areas a tan to brown cast. Roots of SDS-affected plants are reduced and discolored, symptoms that precede foliar symptoms. Severely diseased plants are easily pulled from the ground, and the outer taproot may be blue due to fungal sporulation.

Causal Organism

SDS is caused by the soilborne fungus *Fusarium solani* f. sp. *glycines*. The fungus produces macroconidia (asexually produced spores) and chlamydospores (overseasoning thick-walled spores). Molecular studies of isolates from different states indicate that the fungus is genetically homogeneous and distinct from other, non-SDS-causing *F. solani* isolates that also can infect soybean roots. Our research indicates that the distinctive foliar symptoms are caused by one or more toxins produced by *F. solani* f. sp. *glycines* in infected roots and that are then translocated to the leaves.

Survey

In 1998 and 1999, field surveys conducted by scientists at the University of Illinois and Southern Illinois University showed evidence of SDS throughout the state (Table 1). This disease seems most prevalant when cool, moist conditions occur during the early part of the growing season and, in particular, when moist soil conditions occur again during early flowering. For example, the disease was found less frequently in most of the southern part of the state in 1999 when drought conditions were severe. In both years, counties in the central and eastern portion of the state had the highest incidence of SDS. In general, the severity of SDS was less in 1999 than in 1998, and foliar symptoms were observed 1 to 2 weeks later in 1999 than in 1998.

Soybean Response

Soybean varieties vary in their susceptibility to SDS based on foliar severity ratings. In 1998 and 1999, 597 and 650 commercial soybean entries, respectively, were evaluated for their response to SDS under field and greenhouse conditions. There were large differences in the reaction to SDS based on foliar symptom severity. Some of the better entries included plant introductions that were used in greenhouse screening as partially resistant checks (Table 2). The majority of commercial varieties were susceptible. Based on these studies, it is recommended that varietal selection be the number one management choice because there are differences in varietal reaction to SDS foliar severity ratings.

Table 1 • Occurrence of SDS in soybean fields in Illinois by agricultural statistical districts in 1998 and 1999.[1]

District	Counties 1998	Counties 1999	Fields 1998	Fields 1999	Incidence (%)[2] 1998	Incidence (%)[2] 1999
Central	11	11	555	202	46	68
East	7	7	630	222	43	66
East-southeast	15	15	694	684	21	7
Northeast	11	8	134	160	28	14
Northwest	12	12	182	237	17	22
Southeast	12	12	352	468	32	10
Southwest	12	12	352	783	32	8
West	9	9	135	237	15	15
West-southwest	13	13	517	609	38	5

[1] Unpublished data resulting from a joint survey of the state conducted by soybean researchers at Southern Illinois University and the University of Illinois.
[2] Based on visual observations of leaf symptoms in any part of a given field.

What's Next?

Applied and basic research is being conducted to further our understanding of the pathogen, the disease, and environmental interactions and this research may lead to additional management options. The first line of defense is to plant varieties that are less susceptible to the fungus. The immediate approach is to provide growers with data on varietal response to SDS. Research also is underway for better sources of resistance that can provide highly resistant germplasm for use in breeding programs for the development of more resistant varieties.

Besides searching for sources of resistance, I and others are researching the role of transition zones between areas in the field with severe SDS and those with little or no SDS to explain what field conditions may play a role in SDS development. Fields in which the pathogen is present are likely to develop the disease in subsequent years. Part of our field research is to manage this disease through cultural practices that include minimizing compaction, improving drainage, reducing populations of the pathogen, and limiting other stresses, including soybean cyst nematode. The outcome of these studies should complement the research on host response to *F. solani* f. sp. *glycines*.

Summary

A decade ago, SDS of soybean received only minor attention by growers and researchers in Illinois and in other states. In the last decade, SDS has become a major disease, and research programs have been developed to understand the pathogen, disease development, and how to control the disease. SDS is readily recognized by its distinct symptoms that include mottling and interveinal chlorosis and necrosis on the upper leaves at flowering. It also causes root and crown rot, vascular discoloration of stems, defoliation, and pod abortion. The soilborne fungus *F. solani* f. sp. *glycines* causes SDS. Field patterns of SDS vary from strips to distinct patches to large patches that coalesce to cover extensive areas within a field. The foliar symptoms of the disease normally are observed on plants during the mid- to late reproductive growth stages from mid- to late August. State surveys in 1998 and 1999 showed that SDS occurred in all agricultural statistical districts in Illinois, with some districts having as high as 46 and 68% of fields with SDS in 1998 and 1999, respec-

Table 2 • Rating of soybean varieties for SDS after inoculation with *Fusarium solani* f. sp. *glycines*.[1]

Variety	Source	AUDPC[2]
PI567.374	Plant Introduction	28
PI520.733	Plant Introduction	31
SD95-789	USDA-North	32
M92-1731	SCN	34
MN–0901	University of Minnesota	35
Karno		35
PI567.650B	Plant Introduction	36
DPX 8545 RR	Deltapine	37
D 478	Garst Seed Co.	37
U97-2406	USDA North	37
IA2036	ISU	37
P9363	Pioneer Hybrids	42
MEAN		40

[1] For additional information on varietal response, access http://www.ilsoy.org/99news/Checkoffsos.html
[2] Accumulated foliar severity ratings based on multiple ratings of greenhouse inoculated plants.

tively. Because of the high incidence and increase of inoculum, the disease is likely to remain a major constraint to increased yields. Our research has focused on reducing the occurrence of this disease through soybean varietal selection, breeding, and other means of cultural controls. Every year commercial varieties and other germplasm are screened and scored for resistance to SDS. Varietal selection currently is the best option in managing this disease.

Acknowledgements

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Soybean Cyst Nematode Update – Races and Resistance

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Races

Soybean cyst nematode, *Heterodera glycines*, probably is the most severe pest of soybean in the United States, causing estimated annual losses of at least 80 million bushels (Doupnik 1993, Wrather et al. 1995). Within 3 years of the discovery of soybean cyst nematode in the United States in 1954 (Winstead et al. 1955), researchers reported the ability of the nematode to reproduce on soybean lines that had been considered as highly resistant by Japanese nematologists (Ross and Brim 1957). The term "biological races" was used to describe these soybean cyst nematode populations. Soon after the release of the first soybean cyst nematode-resistant variety 'Pickett' (Brim and Ross 1966), fields in the lower Mississippi Valley were found to have populations of soybean cyst nematode that damaged 'Pickett' (Riggs et al. 1968). These populations of soybean cyst nematode were referred to as a new "biotype." It was apparent that soybean cyst nematode possessed much diversity in its ability to attack various soybean lines and a method was needed to categorize these populations of soybean cyst nematode. A workshop on soybean cyst nematode was held in 1969 and a committee of nematologists and plant breeders was chosen to develop a system to define the ability of this nematode to reproduce on different soybean lines (Golden et al. 1970). The term "race" was designated to define the ability of soybean cyst nematode populations to develop on a set of soybean differential hosts that included soybean cyst nematode-resistant 'Pickett,' 'Peking' (the resistant parent of 'Pickett'), plant introduction (PI)88.788 and PI90.763, and soybean cyst nematode-susceptible 'Lee'. Four races were designated originally. Soon after the race scheme was published, other populations were found that did not fit the scheme of four races. The number of races was expanded to 16 in 1988 (Riggs and Schmitt 1988; Table 1). The designation of a particular race is based on the ability of the soybean cyst nematode population in question to develop females on roots of the soybean differential lines. A plus (+) or a minus (–) is assigned based on a female index, which is a percentage of the number of females that develop on the differential compared with the number that develop on the soybean cyst nematode-susceptible 'Lee.' A plus symbol is assigned when the female index is ≥10% and a minus symbol is assigned when the female index is <10%.

The term "race" was and still is widely used and accepted in nematology and plant pathology to define the ability of a nematode or a pathogen to attack either a specific set of host plants of different species or host plants of the same species. There are conceptual and biological considerations when applying the term "race" to a population of sexually reproducing and highly variable organisms such as soybean cyst nematode. A population may be identified as being race 3, but there are other genotypes within that population. These other genotypes are represented at lower frequencies than the genotype(s) that would provide a "race 3" reaction in our hypothetical population. Even the nematodes that develop to provide the race 3 designation have different genotypes. These considerations have caused some researchers to consider the entire concept of race in soybean cyst nematode as invalid. However, it is obvious that all populations of soybean cyst nematode are not identical in their ability to attack different sources of resistance, and planting a variety that has either a low level of resistance or no resistance to a

virulent population can lead to loss in yield. One source of confusion has been the designation of race 4 when PI88.788, which is the source of resistance to race 4, is listed as a plus symbol in supporting reproduction of race 4 (Table 1). In our experience, populations of race 4 normally have a female index of 17–20%. Additional confusion occurred when some in the agricultural community decided that race 4 did not exist and was actually race 14 and began using the terminology "race 14 formerly race 4." As defined by the race scheme, both race 4 and race 14 are valid, and populations of both can be found in producers' fields.

The race scheme continues to provide a means for communication among soybean breeders, extension personnel, nematologists, and producers. The current system of defining variability in soybean cyst nematode will evolve into another system when the virulence genes in the nematode are mapped and can be defined based on the source of resistance in soybean that they will overcome. Triantaphyllou (1975) provided sound reasoning when he wrote, "Although the genetic structure of field populations does not provide a solid foundation for race designation, recognizing races under the present system may be useful when it clearly characterizes the behavior of field populations. Race designations, however, should be regarded as provisional since gene frequencies change with time in response to selection forces and, therefore, the race status of a population may change accordingly."

Table 1 • Race classification for soybean cyst nematode with differential soybean lines and a female index (FI) (Riggs and Schmitt 1988).

Race	Pickett	Peking	PI88.788	PI90.763	Lee
1	–	–	+	–	+
2	+	+	+	–	+
3	–	–	–	–	+
4	+	+	+	+	+
5	+	–	+	–	+
6	+	–	–	–	+
7	–	–	+	+	+
8	–	–	–	+	+
9	+	+	–	–	+
10	+	–	–	+	+
11	–	+	+	–	+
12	–	+	–	+	+
13	–	+	–	–	+
14	+	+	–	+	+
15	+	–	+	+	+
16	–	+	+	+	+

FI = [(number of females developed on differential)/(number developed on Lee)] x 100; FI = <10%, – and FI ≥10% = +.

A survey of races in 23 counties in Illinois published in 1991 found that 64% of the populations were race 3, 27% were race 1, and the remaining 9% of the populations were races 2, 4, and 5 (Sikora and Noel 1991). Limited data from an ongoing survey indicate that race 3 is still the most common. Although the data are limited and most samples were obtained in central Illinois, it appears that there has not been a major change in the race composition of populations in Illinois. There is concern that after growing resistant varieties for several years, a shift in races might occur as was the case in North Carolina (after resistant varieties had been grown several years, a shift from race 1 to race 2 occurred). Populations of soybean cyst nematode in Illinois should be monitored closely for increases in numbers of soybean cyst nematode on resistant varieties. Sampling for soybean cyst nematode is a key component for long-term control.

Resistance

Nationwide, there are approximately 600 soybean varieties resistant to soybean cyst nematode. In the Midwest, there are >400 varieties available in maturity groups I–IV. Approximately 95% of these resistant varieties derive their resistance from 'Fayette', which was released in 1981 and has the PI88.788 source of resistance (Bernard et al. 1988). There is concern that so much reliance is placed on one source of resistance. Public and private soybean breeding programs are seeking other sources of resistance. Germplasm releases at the University of Illinois have included PI89.772, PI209.332, and Cloud (Nickell et al. 1994a-c). 'Ina' (maturity group IV), which derives its resistance from 'Hartwig' (PI437.654; Anand 1992), was released in 1998 and should be available to producers for the 2000 planting season (Nickell et al. 1999). 'Ina' has a high level of resistance to races 1, 3, and 5 and a moderate level of resistance to races 2 and 14. It has the susceptibility to race 4 found in 'Hartwig.' Earlier maturing varieties with the 'Hartwig' resistance are expected in the near future.

Because the majority of soybean cyst nematode populations in Illinois are race 3, the resistance in PI88.788 will provide good control for most producers. Genotypes of soybean cyst nematode populations characterized as race 1 are variable and different resistance genes may occur in resistant varieties with

the PI88.788. Thus, some varieties may be moderately resistant to soybean cyst nematode race 1 and provide adequate control if crop rotation is practiced and the soybean cyst nematode numbers are reduced to near the threshold for a susceptible variety. Because no resistant variety is resistant to all populations of soybean cyst nematode, and there is no mechanism to do race tests on a large scale, it is imperative that producers sample their fields to monitor the numbers of soybean cyst nematode. If numbers of soybean cyst nematode appear to increase, a longer rotation may be needed or, if available, a different source of resistance may need to be planted. In an 11-year study, rotation of varieties having different sources of resistance (gene deployment) was effective in reducing soybean cyst nematode numbers below the level of detection (Noel and Edwards 1996).

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Genetics of Gray Leaf Spot Resistance

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The foliar disease gray leaf spot of corn, caused by the fungus *Cercospora zeae-maydis* (Tehon and Daniels 1925), has become an economic concern in the midwestern United States within the past 20 years. Although the characteristic rectangular-shaped lesions of this disease were first reported on corn in Alexander County, Illinois, in 1925, only minor outbreaks were reported throughout the southern, eastern, and central corn-growing regions of the United States prior to the early 1980s. Several studies have linked the current prevalence of gray leaf spot in the Corn Belt to the widespread acceptance of conservation tillage beginning in the late 1970s (Roane et al. 1974, Hilty et al. 1979, Rupe et al. 1982, Latterell and Rossi 1983, Payne and Waldron 1983, Ayers et al. 1984, Payne et al. 1987, Donahue et al. 1991, de Nazareno et al. 1993). Fields at the highest risk for gray leaf spot epidemics are those in which management practices leave a large amount of crop residue on the soil surface between seasons of continuous corn. Also at risk are susceptible hybrids planted into conventionally tilled fields or into fields following a noncorn crop where a large percentage of the surrounding farmland is in conservation tillage (Lipps et al. 1998). Management of gray leaf spot through conventional tillage alone in the latter example may not be enough to avoid yield loss when areawide disease levels are severe. Chemical fungicides may be applied to augment a disease management program; however, the relatively low value of commercial field corn produced for grain may preclude chemical use on all but the highest-value corn crops. Because abandonment of conservation tillage on a regional scale is not practical, economical, or environmentally sound, and because the application of chemical fungicides may be noneconomical for grain production, resistant hybrids are the best solution for improved gray leaf spot management.

Most corn hybrids used in the Midwest prior to 1989 had a similar degree of susceptibility to gray leaf spot (Ayers et al. 1984, Lipps et al. 1996). This susceptibility is due in part to the relatively new status of gray leaf spot as a yield-limiting influence within the United States. Germplasm used for corn hybrid development in the Midwest generally has not been subjected to extended periods of selection for resistance. Recently, commercial hybrids with moderate levels of resistance have been marketed and used in the Corn Belt. Although many of these hybrids have greater yield potential than susceptible hybrids when disease pressure is moderate to high, none have the high levels of resistance necessary to avoid loss during severe epidemics (Lipps et al. 1998). Unfortunately, much of the germplasm identified as resistant also has poor agronomic characteristics, including low yield, late maturity, and susceptibility to other diseases (Hilty et al. 1979, Thompson et al. 1987, Elwinger et al. 1990, Ulrich et al. 1990, Bubeck et al. 1993, Graham et al. 1993, Coates and White 1994, Gevers and Lake 1994). These poor agronomic characteristics often reduce economic gains to the producer by contributing to increased grain moisture at harvest, predisposing the crop to pathogens that cause stalk lodging, and reducing the effectiveness of mechanical harvest. These traits complicate breeding for resistance because selection against them must be incorporated into breeding programs.

Generation mean analysis (Manh 1977, Thompson et al. 1987, Coates and White 1998), diallel cross analysis (Ayers et al. 1984, Thompson et al. 1987, Huff et al. 1988, Elwinger et al. 1990, Ulrich et al.

Table 1 • Comparison of yield, moisture, root lodging, stalk lodging, and gray leaf spot severity (1998) between commercial hybrids PIO3406, PIO3489, PIO33A14, and test crosses of FR1064 and seven University of Illinois inbred lines.[a]

Pedigree	Yield (bu/acre)	Moisture (%)	Root lodging (%)	Stalk lodging (%)	GLS severity (% leaf area affected)
DW97041 × LH185	206.4	19.3	1	1	15
DW97040 × LH185	203.7	19.6	1	1	25
PIO33A14	202.5	17.2	1	2	38
FR1064 × LH185	201.1	16.7	1	1	53
DW97052 × LH185	200.8	17.8	1	0	23
DW97029 × LH185	195.0	18.6	0	1	19
DW97031 × LH185	194.6	17.8	1	0	20
DW97038 × LH185	194.6	19.4	0	2	22
DW97034 × LH185	189.6	18.2	0	0	18
PIO34R06	188.4	14.8	2	2	55
PIO3489	179.8	16.2	1	1	54

[a] Test crosses of seven best University of Illinois inbred lines evaluated for gray leaf spot resistance and agronomic characteristics are denoted as DW.

1990, Donahue et al. 1991, Gevers and Lake 1994), and parent progeny correlation (Thompson et al. 1987) have been used to determine the inheritance of resistance to gray leaf spot. Collectively, these analyses reveal that resistance to gray leaf spot is 1) inherited additively; 2) controlled by additive gene action, with possible minor dominant and epistatic contributions; 3) associated with the general combining ability of inbred lines; and 4) controlled by few effective factors.

Recently, restriction fragment length polymorphism technology has been used to identify chromosomal regions from different sources that are associated with resistance to gray leaf spot of corn (Bubeck et al. 1993, Saghai Maroof et al. 1996, Clements 1999). Research at the University of Illinois has focused on the cross of inbreds 061 and FR1141 (Clements 1999). FR1141 is a B73-related inbred developed by Illinois Foundation Seeds, Inc., that is susceptible to gray leaf spot. Inbred 061 is an agronomically poor, unreleased self out of PI320061 identified as having a high level of resistance to gray leaf spot that is highly heritable and easily transferred by backcrossing into B73-type inbreds (Coates and White 1998).

Five chromosomal regions, termed quantitative trait loci (QTL), are of particular interest from the University of Illinois study. These five QTL, located on chromosomes 1, 2, 5, and 7, are significantly associated with relatively large, consistent effects on gray leaf spot resistance in multiple environments. Alleles donated by the resistant parent (061) at these regions contribute to reduced gray leaf spot severity, and account for between 51.0 and 58.7% of the phenotypic variation. Furthermore, these five QTL function regardless of the maturity stage of the host. The QTL identified with alleles from 061 on chromosome 1 accounted for the largest amount of the phenotypic variance at 20.9 to 23.3%. This QTL also was prominently identified in studies of Va14, NC250A, and ADENT (Bubeck et al. 1993, Saghai Maroof et al. 1996); however, the association of alleles donated at this region from NC250A and ADENT with gray leaf spot resistance was not consistent across environments. One region on the long arm of chromosome 2 was identified from NC250A and ADENT as being consistently associated with gray leaf spot resistance across populations and environments (Bubeck et al. 1993). The proximity of this region to the QTL identified from 061 suggests that 061, NC250A, and ADENT may share an analogous genomic region on chromosome 2. Resistance from Va14 appears to be slightly different because a generation- and environmentally dependent QTL was identified on the short arm of chromosome 2 (Saghai Maroof et al. 1996).

Resistance to gray leaf spot has been associated with regions of chromosome 5 from Va14, NC250A, and ADENT (Bubeck et al. 1993, Saghai Maroof et al. 1996). In each of these studies, the regions of interest were significant in only a limited number of environments and populations. Two marker-associated effects were identified on chromosome 5 from 061. The first accounts for between 2.7 and 4.2% of the phenotypic variation; the second accounts for between 8.3 and 9.7% of the variation. These regions

are similar to those identified from Va14, NC250A, and ADENT, indicating that their significance on chromosome 5 is probably not the result of a false positive.

The chromosome 7 QTL identified from 061 accounted for between 5.2 and 11.3% of the phenotypic variation. A similar region was identified in two populations derived from NC250A (Bubeck et al. 1993); however, no marker-associated effect was noted in the ADENT population of the same study. It is possible that 061 and NC250A share an analogous genomic region on chromosome 7, and if so, share genes for resistance in this region that are different than those described from Va14 and ADENT.

Presently, the environment- and maturity-independent QTL identified from the cross of inbreds 061 and FR1141 are being used in a marker analysis program at the University of Illinois. Several inbred lines have been recovered through a series of crossing and selfing cycles with inbreds 061, FR1141, and FR1064. Although test crosses of the resulting lines are not immune to gray leaf spot, many possess the high level of resistance necessary to withstand severe disease pressure in the Corn Belt (unpublished data). The seven best test cross lines from this program in 1998 had an average yield of 197.5 bu/acre, and an average percentage of leaf area blighted by gray leaf spot of 20.4%. This level of susceptibility is approximately half that of commercial hybrids evaluated in the test (Table 1). Despite the high level of resistance observed in the 1998 field trial, it is possible that further breeding work may be needed to introgress all of the QTL identified with resistance alleles from inbred 061 into the seven University of Illinois lines. Thus, molecular marker analysis is forthcoming.

Corn producers will depend on an integrated system of residue management, fungicides, crop rotation, and resistant hybrids to reduce the future impact of gray leaf spot in the United States and abroad. The most economical, sustainable, and efficient component of this system remains the use of resistant hybrids.

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Recovery Time: Herbicides and Interactions with Diseases (Objective IV – IL/IA Yields Project)

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In 1996, a group of approximately 30 scientists from several universities and several members of the Illinois and Iowa Soybean Checkoff Boards met to discuss a research project. The major focus of this project was to study the interactive effects of herbicide injury, nematodes, and plant diseases on soybean growth, development, and varietal yield under different environmental conditions. The project was designed to gain a better understanding of how management practices can be altered to reduce stress, which can lead to increased yields. There were five main components and they became known as the five objectives: I) Determine the yield potential of soybean varieties under various management conditions. II) Determine the effect of herbicides on soybean growth, development, and yield. III) Determine the effect of soybean cyst nematode on plant growth, development, and yield. IV) Determine possible interactions between soybean cyst nematode, sudden death syndrome (SDS), brown stem rot, and other plant diseases and insects with herbicides, especially related to plant growth and yield. V) Incorporate information from objectives I–IV into a soybean model to study plant stress associated with plant disease, soybean cyst nematode, and herbicide injury, as well as yield reductions.

The research groups were comprised of the three of us from the University of Illinois; Micheal Owen, Greg Tylka, Larry Pedigo, and XB Yang from Iowa State University; Oval Myers, Mike Schmidt, and Bryan Young from Southern Illinois University; and Graig Grau, Ed Oplinger, and Ann McGuidwin from the University of Wisconsin.

Description of Experiments

A total of 9 to 13 locations per year in Illinois, Iowa, and Wisconsin was selected based on previous history of one or more specific plant diseases. For example, a site with high populations of soybean cyst nematode was selected in each state. Commercial soybean varieties with specific disease resistance and herbicide tolerance were selected, and 4–8 varieties were planted at each location. Herbicide treatments were selected on use, mode of action, or previous research and included Prowl (at planting), Pursuit (postemergence), Blazer (postemergence), Synchrony (postemergence), Roundup (postemergence), Galaxy (postemergence), and a hand-weeded control. Synchrony and Roundup were applied to the appropriate tolerant soybean varieties. Plots were 25 ft in length and 8 rows in width, with 30-in. row spacing. Four rows were used for destructive sampling, and four rows were used for yield. Data collected included estimates of soybean cyst nematode populations in all fields prior to planting; plant populations; plant biomass (several times during the growing season); leaf area index (LAI) measurements, which are designed to measure reduction in plant canopy; plant disease isolation and ratings (several times during the growing season); visual herbicide injury ratings; plot yields; yield components; and final soybean cyst nematode populations.

Results and Discussion

In two locations, there was slight injury associated with Roundup on Roundup Ready soybean varieties;

however, no reduction in plant growth, LAI values, or yield was detected compared with the hand-weeded control. Similarly, the application of Synchrony did not affect plant growth or yield in any of the trials. Neither Roundup nor Synchrony increased or decreased any of the plant diseases evaluated in this study.

The postemergence herbicides Pursuit, Blazer, and Galaxy caused foliar injury in all 3 years, but the severity was influenced by temperature. With high temperatures, both prior to and after spraying, injury tended to be more severe. Recovery also was dependent upon temperature and moisture. When conditions after applying the herbicides were cool with sufficient moisture, recovery was rapid; however, when soybean plants were under stress, recovery was delayed. In some years, the recovery, based on LAI evaluations, was not equal to the hand-weeded control, and yields were reduced.

Interaction with Soybean Cyst Nematodes

The initial population of soybean cyst nematodes was approximately 1,000–4,000 eggs/100 cc soil (threshold levels are approximately 400–500 eggs/100 cc soil). We also had a field nearby that had very low levels of soybean cyst nematodes, so we could compare the effect of herbicides on soybean cyst nematode-resistant and -susceptible varieties in high and low nematode populations. For soybean cyst nematode-resistant and especially soybean cyst nematode-susceptible varieties, herbicide injury was greater with high soybean cyst nematode populations. In addition, recovery from herbicide injury for soybean cyst nematode-resistant varieties was delayed by 10–14 days compared with the field with low soybean cyst nematode populations. Soybean cyst nematode-susceptible varieties did not recover from the combined stress of herbicide injury plus soybean cyst nematode infection and suffered severe yield reduction. In the field with low soybean cyst nematode populations, recovery from herbicides was rapid, generally 12–16 days, and yields were not reduced compared with the hand-weeded control. Soybean cyst nematode populations at the end of the growing season were affected by both variety and herbicide. There were much higher populations of nematodes present after growing susceptible varieties, but there also was a significant difference in nematode populations among soybean cyst nematode-resistant varieties. 'Jack' had the lowest reproductive rate of the varieties tested. Herbicides also affected reproduction, but this effect varied with year and location, with no clear conclusions. The summary from this section is to determine if soybean cyst nematode populations are above threshold and to implement a management strategy to control soybean cyst nematodes. If soybean cyst nematode is controlled, additional stress factors have less impact than if they are combined.

Interaction with Other Plant Diseases

Our initial hypothesis was that herbicide stress may increase the incidence of plant diseases. A preliminary study in 1996 showed that the application of Galaxy increased the incidence of Rhizoctonia root rot in a Roundup Ready soybean variety from 12 to 88% compared with Roundup. We confirmed that postemergence herbicides could increase root diseases, but root diseases also could increase injury ratings from herbicides. It really depends upon the onset of the disease. If the seedlings have root infection prior to herbicide application, then the herbicide injury can be greater and recovery delayed. However, if herbicide injury occurs first and is followed by additional stress (e.g. moisture and temperature stress), an increase in plant disease can occur. Usually, the increase in plant disease after herbicide application does not result in reduced yields.

In one year, both the Southern Illinois University and Iowa State University researchers found a reduction in SDS associated with the application of Blazer, however, that observation has not been confirmed. We found no effect of Pursuit or Blazer on white mold or other diseases. We did find a number of soilborne fungi that may be causing root diseases that have not been identified. Additional research is needed to confirm that these organisms are pathogens of soybeans.

Proceedings

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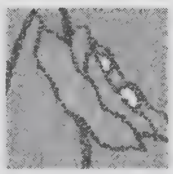
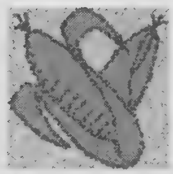

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 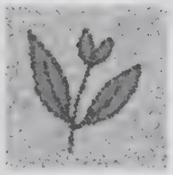 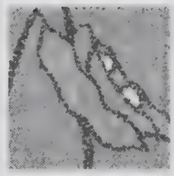 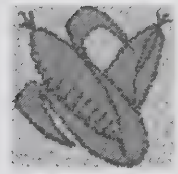

2001 Illinois Crop Protection Technology Conference Planning Committee

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Program
January 9 & 10, 2001

Tuesday Afternoon, January 9

Illini Rooms

1:00 p.m. Welcome, Opening Remarks and Informational Items
Kevin Steffey

Keynote Session: Agricultural Biotechnology – Scientific and Social Issues
(1.5 CCA credits in Pest Management)
Todd Gleason, Moderator

1:15 Overview of the Issues: What's Your Ag Biotechnology IQ?
Peter Goldsbrough

1:40 GMOs: Gourmet Delights or Frankenfoods?
Bruce Chassy

2:05 Constructing Markets for GMO Crops – Responding to Consumer and Public Interest
Randall Westgren

2:30 Handling of GM Crops Issues by the Media
Eric Abbott

2:55 Panel Discussion

3:25 Break

New Developments from Industry
George Czapar, Moderator

3:45 Aventis

3:55 Monsanto

4:05 FMC

4:15 DuPont

4:25 Dow AgroSciences

4:35 Bayer

4:45 BASF

4:55 Syngenta

5:05 Valent

5:15 – 6:30 **IFCA Sponsored Mixer –** Illini Union Ballroom

This mixer is sponsored by the Illinois Fertilizer and Chemical Association, and it is intended for everyone to meet with speakers, sponsors, and committee members in an informal atmosphere.

Wednesday Morning, January 10

Symposia A and B running concurrently with Workshops 1–7 from 8:30–10:00 a.m.

Symposium A: Emerging Crop Protection Issues in Corn – Illini Room A
(1.5 CCA credits in Pest Management)
Lou Chapko and Dave Thomas, Moderators

8:30 a.m. Monarchs and Bt: Sorting Out the Facts
Kevin Steffey

8:45 Transgenic Insecticidal Cultivars for Corn Rootworms: Meeting the Challenges of Resistance Management
Michael Gray

9:00 Hybridization Among the Amaranths: Implications for Herbicide Resistance Evolution
Patrick Tranel

9:15 Resistance Management Concerns in Weed Science
Mike Owen

9:30 Panel Discussion

Symposium B: Emerging Crop Protection Issues in Soybeans – Illini Room B
(1.5 CCA credits in Pest Management)
Joe Bruce and David Shenaut, Moderators

8:30 New Strategies for an Old Pest: Rethinking Bean Leaf Beetle Management
Marlin Rice

8:45	Fall Behind or Spring Ahead: Where are Fall-Applied Herbicides Going? *Christy Sprague*
9:00	What Did We Learn About Soybean Aphids in 2000? Expectations for 2001 *John Wedberg*
9:15	Soybean Viruses in Illinois *Glen Hartman*
9:30	Panel Discussion

Workshops 1–7 running concurrently with Symposia A and B from 8:30–10:00 a.m.

Workshop 1: Seed Treatments for Soybean, Corn and Wheat – Illini Union Room 209
Wayne Pedersen

The instructor will discuss current findings on fungicide seed treatment of corn, wheat, and soybean, including application and effectiveness of seed treatment on disease management and impact on yield. (1.5 CCA credits in Pest Management)

Workshop 2: Digital Imaging: Get the Picture – Illini Union Room 211
Dennis Bowman and Robert Bellm

The use of digital cameras, e-mail and the Internet has created a new easily accessible way for pest diagnoses to be made. This workshop will focus on identification of crop plant, insect, weed and disease traits that are critical for accurate diagnosis. (1.5 CCA credits in Pest Management)

Workshop 3: Management, Organic Matter and Carbon Sequestration – Illini Union Room 314A
Michelle Wander

Interest in management of soil organic matter and carbon sequestration has grown during the last few years. The instructor will address why and how, focusing upon relevant research, programs, and policies. (1.5 CCA credits in Soil & Water Management)

Workshop 4: Herbicide Behavior in the Soil Environment – Illini Union Room 314B
Bill Simmons

Learn how application timing, weather, and soil conditions affect herbicide efficacy. What is the potential carryover or crop response to soil-applied herbicides? Get a comprehensive review of how currently used corn and soybean herbicides behave in the soil. (1.5 CCA credits in Soil & Water Management)

Workshop 5: Plant Stresses in Corn and Soybean – Illini Union Room 404
Emerson Nafziger

What is crop stress? How can we tell if crops are stressed? Why and how does stress affect yield prospects? What, if anything, can be done to prevent or alleviate crop stress? Obtain answers to these and other questions by attending this session. (1.5 CCA credits in Crop Management)

Workshop 6: Tough Weeds on the Horizon –Know Them and Attack Them – Illini Union Room 405
Jerry Doll

Like many aspects of farming, weeds change over time. This workshop will highlight many of these emerging weed problems, and you will learn how to identify and manage them. Examples will concentrate on winter annual and perennial species. (1.5 CCA credits in Pest Management)

Workshop 7: Weed Population Dynamics – Illini Union Room 406
Robert Hartzler

Changes in weed infestations may be as simple as an increase in the density of one species following a year of poor control, or may involve a shift in genetic composition within a weed species following repeated use of a herbicide. The adaptability of weed populations is the primary reason why weeds are a continuous problem in crop production. The goal of weed management should be to reduce the occurrence of rapid shifts in weed populations. This workshop will focus on factors that influence population dynamics and design of weed management systems to reduce negative impacts of adaptation of weeds. (1.5 CCA credits in Pest Management)

10:00–10:30 **Break** – Illini Room C and South Lounge

Symposia A and B and Workshops 1–7 repeated concurrently from 10:30 a.m.–12:00 p.m.

Symposium A (repeated): Emerging Crop Protection Issues in Corn – Illini Room A

Symposium B (repeated): Emerging Crop Protection Issues in Soybeans – Illini Room B

Workshop 1 (repeated): Seed Treatments for Soybean, Corn and Wheat – Illini Union Room 209

Workshop 2 (repeated): Digital Imaging: Get the Picture – Illini Union Room 211

Workshop 3 (repeated): Management, Organic Matter and Carbon Sequestration – Illini Union Room 314A

Workshop 4 (repeated): Herbicide Behavior in the Soil Environment – Illini Union Room 314B

Workshop 5 (repeated): Plant Stresses in Corn and Soybean – Illini Union Room 404

Workshop 6 (repeated): Tough Weeds on the Horizon – Know Them and Attack Them – Illini Union Room 405

Workshop 7 (repeated): Weed Population Dynamics – Illini Union Room 406

12:00 p.m. **Lunch**

Wednesday Afternoon, January 10

Symposia C and D running concurrently with Workshops 8–14 from 1:30–3:00 p.m.

Symposium C: Precision Farming and New Innovations in Crop Protection – Illini Room A (0.9 CCA credit in Crop Management, 0.3 CCA credit in Nutrient Management, 0.3 CCA credit in Pest Management) *Dennis Bowman and Robert Bellm, Moderators*

1:30 p.m. Variable Rate Fertilization
Don Bullock

1:45 NASA Remote Sensing: Status of Weed Detection Research Efforts
Ken Copenhaver

2:00 Sensor-Based Precision Farming System
Lei Tian

2:15 Using Precision Farming Technology in Identity Preserved Systems
Todd Peterson

2:30 Panel Discussion

Symposium D: Emerging Issues in Water Quality and Nutrient Management – Illini Room B (1.5 CCA credits in Soil & Water Management) *A.G. Taylor and Jean Trobec, Moderators*

1:30 Nitrogen Management: What We Know Now — Will it Make a Difference?
Bob Hoeft

1:45 Approaches to Protecting Water Quality: Voluntary or Regulatory
George Czapar

2:00 Gulf of Mexico Hypoxia and Midwest Agriculture
Dennis McKenna

2:15 Ecologically-Based Water-Quality Criteria for Nutrients
David Pfeifer

2:30 Panel Discussion

Workshops 8–14 running concurrently with Symposia C and D from 1:30–3:00 p.m.

Workshop 8: Specialty Corn and Soybeans – Illini Union Room 209
Pete Fandel

Information presented in this workshop will focus on results of the on-farm specialty crop trials, which show the advantages and disadvantages of different specialty crops based on yield, profit, agronomic traits, and output trait analysis. The instructor will demonstrate on-line fact sheets and budget/profit calculators. (1.5 CCA credits in Crop Management)

Workshop 9: Western Corn Rootworms in the 21st Century: New Research on an Old Problem – Illini Union Room 314A
Joseph Spencer, Susan Ratcliffe, Scott Isard, Eli Levine, Christopher Pierce, and Silvia Rondon

The instructors will discuss the current status of rotation resistance in populations of western corn rootworms in Illinois. Highlights will include the latest information about the effects of planting dates on egg laying by western corn rootworm females, migratory flight and behavior, and statewide abundance of western corn rootworms in soybean. An

updated economic threshold, based on results from on-farm research, will be presented. (1.5 CCA credits in Pest Management)

Workshop 10: Troubleshooting Field Crop Problems – Illini Union Room 314B
Suzanne Bissonnette and Dave Feltes

Draw on your own field experiences to see if you can diagnose the field crop injury problems presented during this workshop. The instructors will challenge you with examples of crop injury caused by insects, diseases, herbicides, and abiotic problems and will discuss their resolution. (1.5 CCA credits in Pest Management)

Workshop 11: Sudden Death Syndrome of Soybean – Illini Union Room 404
Darin Eastburn and Loretta Ortiz-Ribbing

Information presented during this workshop will include an update on recent research to evaluate host resistance to SDS and to determine the effects of environmental factors on development of SDS. Diseased specimens and other materials will be available to give participants a chance to practice evaluating plants for signs and symptoms of SDS. (1.5 CCA credits in Pest Management)

Workshop 12: Soybean Cyst Nematode (SCN) Biology, Sampling and Resistance – Illini Union Room 405
Dale Edwards and Brian Diers

Instructors will discuss the biology and management of soybean cyst nematodes, providing the most current information on breeding for SCN resistance and the current status of resistant varieties. (1.5 CCA credits in Pest Management)

Workshop 13: Understanding Herbicide Modes of Action: Invaluable in Diagnosing Herbicide Injury Symptoms – Illini Union Room 406
Dean Riechers and Lawrence Steckel

A working knowledge of herbicide mode of action can be beneficial when planning a weed management program. Although herbicides should provide good weed control without adverse effects on the crop, herbicide injury to crops occurs relatively frequently. The instructor will discuss various modes of action of herbicides commonly used in corn and soybean production, injury symptoms associated with herbicide families, and safeners used to prevent herbicide injury. (1.5 CCA credits in Pest Management)

Workshop 14: Secondary or Primary Insects? Will Grape Colaspis and Companions Change Our Management Strategies in Corn – Illini Union Room 407
Kevin Steffey

Grape colaspis, southern corn leaf beetles, white grubs, and wireworms have become problematic in several states. Will continued mild winters and early planting, the loss of some soil insecticides, and the advent of transgenic corn for rootworm control raise the status of these secondary pests? The instructor will provide an overview of our state of knowledge about these pests and how to manage them. (1.5 CCA credits in Pest Management)

3:00–3:30 **Break** – Illini Room C and South Lounge

Symposia C and D and Workshops 8–14 repeated concurrently from 3:30–5:00 p.m.

Symposium C (repeated): Precision Farming and New Innovations in Crop Protection – Illini Room A

Symposium D (repeated): Emerging Issues in Water Quality and Nutrient Management – Illini Room B

Workshop 8 (repeated): Specialty Corn and Soybeans – Illini Union Room 209

Workshop 9 (repeated): Western Corn Rootworms in the 21st Century: New Research on an Old Problem – Illini Union Room 314A

Workshop 10 (repeated): Troubleshooting Field Crop Problems – Illini Union Room 314B

Workshop 11 (repeated): Sudden Death Syndrome of Soybean – Illini Union Room 404

Workshop 12 (repeated): Soybean Cyst Nematode (SCN) Biology, Sampling and Resistance – Illini Union Room 405

Workshop 13 (repeated): Understanding Herbicide Modes of Action: Invaluable in Diagnosing Herbicide Injury Symptoms – Illini Union Room 406

Workshop 14 (repeated): Secondary or Primary Insects? Will Grape Colaspis and Companions Change Our Management Strategies in Corn – Illini Union Room 407

5:00 Adjourn

Program Participants

Abbott, Eric. Professor, Greenlee School of Journalism and Mass Communication, and Coordinator, Technology and Social Change Program, Iowa State University, Ames, IA.

Bell, Matt. Formerly with Illini FS, Ogden, IL.

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Bissonnette, Suzanne. Extension Educator-IPM, Champaign Extension Center, University of Illinois Extension, Champaign, IL.

Bowman, Dennis. Extension Educator in Crop Systems, Champaign Extension Center, University of Illinois Extension, Champaign, IL.

Bruce, Joe. Research and Development Specialist, Novartis Crop Protection, Dewey, IL.

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Burling, Lloyd. President, Illinois Fertilizer and Chemical Association, St. Anne, IL.

Chapko, Louis. Technical Information Manager, Pioneer Hi-Bred International, Inc., Bloomington, IL.

Chassy, Bruce. Executive Associate Director, Biotechnology Center, University of Illinois, Urbana-Champaign, IL.

Clarkson, Lynn. President, Clarkson Grain Company, Cerro Gordo, IL.

Copenhaver, Ken. Midwest Program Manager, Spectral Vision, Urbana, IL.

Czapar, George. Extension Educator in IPM, Springfield Extension Center, University of Illinois Extension, Springfield, IL.

Diers, Brian. Associate Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Doll, Jerry. Professor, Department of Agronomy, University of Wisconsin, Madison, WI.

Eastburn, Darin. Associate Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

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Fandel, Pete. Unit Educator in Crops, Woodford County, University of Illinois Extension, Eureka, IL.

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Hartman, Glen. USDA/ARS Plant Pathologist and Associate Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Hartzler, Robert. Professor, Department of Agronomy, Iowa State University, Ames, IA.

Hoeft, Robert. Professor and Extension Specialist, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Isard, Scott . Associate Professor, Department of Geography, University of Illinois, Urbana-Champaign, IL.

Keane, Ed. District Sales Manager, Aventis, Taylorville, IL.

Levine, Eli. Research Entomologist, Illinois Natural History Survey, Urbana-Champaign, IL.

McKenna, Dennis. Water Issues Advisor, Illinois Department of Agriculture, Springfield, IL.

Nafziger, Emerson. Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Ortiz-Ribbing, Loretta. Visiting IPM Educator, Champaign Extension Center, University of Illinois Extension, Champaign, IL.

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Ratcliffe, Susan. Extension Specialist, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Rhodes, Don. Agronomist, Burrus Power Hybrids, Arenzville, IL.

Riechers, Dean. Assistant Professor, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Rice, Marlin. Professor and Extension Specialist, Department of Entomology, Iowa State University, Ames, IA.

Rondon, Silvia. Graduate Research Assistant, Department of Crop Sciences, University of Illinois, Urbana-Champaign, IL.

Shenaut, David. Agronomic Research Manager, Monsanto Company, Mahomet, IL.

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Tian, Lei. Assistant Professor and Extension Specialist, Department of Agricultural Engineering, University of Illinois, Urbana-Champaign, IL.

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Trobec, Jean. Director, Government Relations, Illinois Fertilizer and Chemical Association, St. Anne, IL.

Wander, Michelle. Associate Professor, Department of Natural Resources and Environmental Sciences, University of Illinois, Urbana-Champaign, IL.

Wedberg, John. Professor and Extension Specialist, Department of Entomology, University of Wisconsin, Madison, WI.

Westgren, Randall. Associate Professor, Department of Agricultural and Consumer Economics, University of Illinois, Urbana-Champaign, IL.

Wolff, Elaine. Program Director, Conferences and Institutes, University of Illinois, Urbana-Champaign, IL.

Overview of the Issues: What Is Your Agricultural Biotechnology IQ?

Peter Goldsbrough

Introduction

Selection of plants with modified characteristics has been central to the development of agriculture over the past 10,000 years. In the past 100 years, progress in identifying plants with desirable combinations of traits has been accelerated by applying the principles of genetics. Discovery of the structure of DNA almost 50 years ago sparked the development of molecular biology, the discipline that has given birth to modern biotechnology. The process of gene discovery has now advanced to a point where we are swamped by genetic information. The complete genetic instructions for many microbes and one plant are known. The first draft of the human genome manuscript has been completed and is being edited and verified before final publication within the next few years.

It is little more than 20 years since the first plant genes were isolated and characterized. Perhaps even more surprising is that the first transgenic or genetically modified (GM) plants were produced as recently as 1983. The technology for isolation and manipulation of genes combined with the ability to transfer genes into plants has led to the development of transgenic crops. The first of these agricultural biotechnology products, the Flavr Savr tomato, was introduced in 1994. Although this product was a commercial failure, it was followed by several others, such as Roundup Ready soybean, that have been readily adopted by farmers in North America and elsewhere, and have been widely accepted by consumers in these regions. For products such as Roundup Ready soybean, fear of losing export markets has been a primary factor in restricting even wider planting of these varieties.

What Is the Agricultural Biotechnology "Revolution"?

Genetic diversity within a species is the raw material used by plant breeders to develop improved varieties. Sometimes, the pool of genes available to a plant breeder can be expanded by inclusion of closely related species that can be crossed with the crop plant. The skill of the plant breeder lies in identifying the best sources of genes and in selecting lines that contain the best genetic combinations for specific applications. Transgenic plant technology can be considered revolutionary in that it eliminates the limitations imposed by sexual compatibility. A tomato breeder is no longer restricted to the genetic diversity available in collections of *Lycopersicon esculentum* and a small number of related species from South America. Instead, the breeder can consider using genes from any organism—plant, animal, or microbe—to improve tomatoes.

Although these genes can come from any organism, bacteria have been a favored source of genes for the first generation of transgenic crops. There are a number of explanations for this trend:

- There is tremendous diversity among bacteria. Bacteria can be found growing in almost every environment, from hot springs to heavily polluted industrial brownfield sites.

- Identifying bacteria with unique metabolic properties, such as the ability to tolerate or metabolize a herbicide, can be straightforward.
- Isolation of genes from bacteria is simpler than isolation of genes from plants or animals. However, large-scale sequencing programs now make identification of genes more a computer exercise than a complex experimental procedure.

For these genes to function appropriately in a transgenic plant, they must be modified by the addition of regulatory sequences that control where, when, and to what level they are expressed. Genes can be transferred into plants using either a biological vector (*Agrobacterium tumefaciens*) or physical methods such as particle bombardment. There are still limitations on gene transfer into plants. The process is very inefficient for some species, thereby delaying the development of GM products for some crops. In crops for which transformation (gene transfer) is more routine, varieties with good agronomic characteristics frequently are recalcitrant to genetic modification. Therefore, genes are first moved into varieties that can be transformed efficiently, and then transferred by conventional breeding into elite germplasm. These and other considerations, such as regulatory approval, mean that development of GM crops is, and will likely remain, a lengthy process.

Current Status

Biotechnology has had an impact on three field crops in the United States over the past 5 years—soybean, corn, and cotton. More than half the acreage planted with soybean and cotton in 2000 was genetically modified via biotechnology; approximately one-quarter of the corn acreage was transgenic. The traits that have been altered in these crops are herbicide tolerance and insect resistance. The promise of this technology has been that it will improve the efficiency of crop production and simplify the methods used for pest control. Rapid adoption of some GM crops indicates widespread acceptance by producers. However, there has been a debate about the impact of GM crops on pesticide use. But there are a variety of methods to measure pesticide use. A recent United States Department of Agriculture Economic Research Service report indicated that use of GM crops has resulted in small reductions in the number of pesticide applications and the total amount of herbicides and insecticides used on these crops. The first commercially released transgenic crops were not designed to eliminate pesticide use, but rather to change pesticide selection. Increased use of a herbicide such as Roundup, which is widely recognized to have relatively low toxicity and short persistence in the environment, is an additional benefit resulting from adoption of GM crops. There is also good evidence that *Bacillus thuriengiensis* (Bt) corn has lower levels of dangerous mycotoxins because the reduced insect feeding provided by Bt toxin also reduces infection by fungal pathogens. Although these are significant results, the first wave of biotechnology products has had essentially no impact on the general public and the food products that are available in the grocery store.

What Are the Issues Surrounding Agricultural Biotechnology?

New technologies are seldom immune from public scrutiny of their merits. History abounds with examples of opposition to technological developments that were perceived to have a negative impact on economic, environmental, or social factors. Biotechnology has been subjected to such analysis. Although applications of these methods in medicine have been widely accepted, agricultural uses have drawn much more opposition. There are four main areas of concern of these developments: ethical; environmental; food safety; and structural, or economic.

Ethical concerns about the use of biotechnology in agriculture include religious and metaphysical beliefs that humankind should not meddle in this way with the plants and animals used to provide food. Beliefs that may not be based on scientific evidence influence our choice of foods in many ways.

The environmental issues associated with GM crops include the possibility that these plants will themselves become pests that cannot be controlled, the potential for transfer of genes to other plants, impact of plant-produced pesticides on other organisms, and the development of pests with resistance to these control measures. One concern is that after the "genetic genie" is released in the form of GM crops, it cannot be recalled or removed from the environment like a chemical pollutant. Instead, this "pollutant" may become a more invasive form of biological pollution. The agencies responsible for regulating the use of GM crops in the United States

have taken the position that the technology used to produce these crops is less of an issue than the traits that have been altered. Requests for extensive long-term testing of GM crops before they are made available for commercial release have been rejected, and most GM varieties have been approved for distribution.

Potential food safety issues for GM crops include the possible introduction of toxins or allergens into the food chain, altering the nutritional composition of foods, and effects on microbes. The U.S. Food and Drug Administration is revising its procedures to deal with these issues. Clearly there is the potential for biotechnology to produce crops that have these hazards, although the likelihood that they would reach the food supply is debatable. Labeling of foods that are derived from GM crops has been proposed to provide consumers with information to allow them to choose whether to eat these foods. However, opponents of labeling question the need for such measures if there are no known safety concerns and suggest that mandatory labeling is designed to increase costs and raise barriers to the introduction of these products.

Concerns have been raised about the impact of biotechnology on the economic structure of agriculture. Consolidation of seed companies and chemical suppliers combined with increased vertical integration of agricultural production are cited as threatening the ability of farmers to operate independently. The goal of delivering value-added products to the producer in the form of seeds rather than chemicals has driven the restructuring of seed and chemical industries. Ownership of technology in the form of genes and their application to agriculture raises concerns that extend beyond the U.S. farm belt. Much of the international opposition to GM crops is aligned with movements that want to halt the global influence of multinational corporations and promote a restructuring of agriculture.

Future Developments

Are we on the threshold of another technological revolution? The industrial revolution was driven by physics and engineering, chemistry powered the next era of discovery, and we are still coming to terms with the new age of information and communication. The methods that organisms use to encode and translate biological information have been revealed in the last half century. However, it is only within the past 15 years that these discoveries have led to products ranging from new drugs to enzymes for food processing. Genetically modified crops are one of the more recent additions to this spectrum of products. If consumers accept this technology, there is likely to be a rapid expansion of this sector; some predict that within 20 years virtually all crops will be transgenic, including those for which gene transfer technology is not yet available. Under this scenario, what might be available in the future?

- Current gene transfer procedures use either antibiotic or herbicide resistance genes to identify and select rare transformed plant cells. Methods will be available to remove these genes after their purpose has been served. These methods also will eliminate concerns about the environmental and food safety impact of these genes. Gene transfer methods are likely to become more predictable in terms of outcome, potentially reducing the development time for these products.
- The number of genes that can be transferred into a plant will increase. The GM crops available now contain just one or two new genes, which limits the traits that can be manipulated. As the capability to add more genes is developed, complex characteristics will be targeted, and the potential of metabolic engineering may be realized.
- The genes used to modify crop plants will come from a wider range of organisms. The possibility that genes from unusual animals will be used remains, but more likely is an increased use of plant genes. As the functions of plant genes are revealed, a process that has only just started, these genes will become candidates for use in crop modification. Traits such as plant architecture, flowering, and environmental adaptation will become amenable to manipulation.
- Manipulation of "input traits" will expand. Targets will include further protection against pests and pathogens, and environmental stress tolerance. Production of hybrids (and resulting yield gains) will be facilitated by development of transgenic male sterility systems. Crops will be developed that are more precisely tailored for animal feeding by modifying traits such as amino acid composition and phosphorous availability.
- The impact of GM crops will extend beyond the farm gate and processing plant to be felt more directly by the consumer. Crop plants with improved nutritional properties, including

elevated levels of vitamins, minerals, and health-promoting compounds, will be available and will require identity preservation.

Conclusion

Introduction of the first products of agricultural biotechnology has not been without controversy. Growers in the United States have adopted these transformed crop varieties rapidly, but a number of groups have voiced opposition. Consumer confidence in the overall safety of the food supply is likely to be critical for continued acceptance of products derived from these crops, especially while there are few direct benefits of biotechnology for the consumer. However, we are at the dawn of an era when the application of discoveries in plant science through biotechnology can have a radical effect on how agricultural crops are produced and used.

GMOs: Gourmet Delights or Frankenfoods?

Bruce Chassy

This section begins with a discussion of issues relevant to safety evaluation of recombinant DNA biotechnology-derived foods, including the concept of substantial equivalence, safety of introduced genetic material and gene product, unintended effects, allergenicity, and products without conventional counterparts. It is followed by the scientific consensus of international scientific groups regarding safety of rDNA biotechnology-derived foods.

Issues Relevant to Safety Evaluation

Food manufacturers are required by law to ensure the safety and quality of their products regardless of the source or identity of the ingredients. Traditional foods are viewed by the Food and Drug Administration as "safe" based on a long history of use. The consuming public also views traditional foods as safe. However, many traditional foods contain naturally occurring toxins that can present hazards to consumers under some circumstances of exposure. Fortunately, in most circumstances, these naturally occurring toxins are present in concentrations that are not hazardous to consumers ingesting typical quantities of the food prepared under typical conditions. Also, some traditional foods are allergenic to some consumers, even though they are safe for the vast majority of consumers.

New foods produced through conventional breeding or introduced into the marketplace from other parts of the world are not required to undergo any type of safety assessment. They are assumed to be safe because they are comparable to other varieties (if newly introduced through conventional breeding) or because they have been safely consumed in other parts of the world. In fact, these newly introduced foods may contain numerous unique components that are not individually or collectively assessed for safety.

In contrast, products derived through rDNA biotechnology are assessed for safety before their introduction into the food marketplace. Food manufacturers also must ensure the safety and quality of products that contain ingredients derived from rDNA biotechnology. In 1992, FDA provided a general outline for the safety assessment of rDNA biotechnology-derived food products based on risk analysis related to the characteristics of the products (FDA 1992). All of the existing foods produced using rDNA biotechnology have undergone a rigorous science-based safety assessment focusing on the characteristics of the products, especially the unique components. While this practice has been voluntary in the United States, FDA announced in May 2000 that it intends to propose a premarket notification system for rDNA biotechnology-derived foods that would make this unofficial policy into a regulatory requirement (HHS, 2000). Thus, in practice, the safety assessment of foods derived using rDNA biotechnology has been more stringent than for conventionally derived products.

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Substantial Equivalence

In the safety assessment of rDNA biotechnology-derived foods, it is helpful to compare the new plant variety to its traditional counterpart because the counterpart has a history of safe use as a food. The concept of substantial equivalence effectively focuses the scientific assessment on potential differences that might present safety or nutritional concerns.

Substantial equivalence is not an absolute determinant of safety per se, since compositional changes in an rDNA biotechnology-derived food may have no impact on the safety of the food. However, substantial equivalence provides a process to establish that the composition of the plant has not been changed in such a way as to introduce any new hazards into the food, increase the concentration of inherent toxic constituents, or decrease the customary content of nutrients. For example, high-oleic-acid soybean oil from rDNA biotechnology-derived soybeans has an oleic acid concentration that falls outside the range typically found in soy oils. From a scientific perspective, this food is nevertheless considered safe, based on scientific knowledge about the safety of oleic acid, a common fatty acid in foods.

A determination of substantial equivalence considers the intentional and unintentional effects of genetic modification, and includes an evaluation of phenotypic and compositional characteristics. With respect to food safety, substantial equivalence involves the quantitative assessment of the concentration of inherent constituents in the modified food, compared to the often wide range typically found in its traditional counterpart, under similar food production conditions.

Most food sources (e.g., soybeans, corn) are exceedingly complex mixtures that vary widely in composition, so it is necessary to consider all of the factors that determine the normal range of variation (IFBC, 1990). Key constituents measured include nutrients, such as proteins, fats, carbohydrates, vitamins, and minerals, as well as inherent antinutritional factors, toxins, and allergens (Miraglia et al., 1998). The breadth of technology used to measure these constituents is evolving rapidly, with new methods available to assess the integrity of metabolic pathways and to measure secondary metabolites, functional proteins, and gene expression at the molecular level.

A recent report (FAO/WHO, 2000) of the Food and Agriculture Organization of the United Nations (FAO) and the World Health Organization (WHO) considered the concept of substantial equivalence:

> A comparative approach focusing on the determination of similarities and differences between the genetically modified food and its conventional counterpart aids in the identification of potential safety and nutritional issues and is considered the most appropriate strategy for the safety and nutritional assessment of genetically modified foods.
>
> The Consultation was of the view that there were presently no alternative strategies that would provide a better assurance of safety for genetically modified foods than the appropriate use of the concept of substantial equivalence. Nevertheless, it was agreed that some aspects of the steps in safety assessment process could be refined to keep abreast of developments in genetic modification technology. The concept of substantial equivalence was developed as a practical approach to the safety assessment of genetically modified foods. It should be seen as a key step in the safety assessment process although it is not a safety assessment in itself; it does not characterize hazard, rather it is used to structure the safety assessment of a genetically modified food relative to a conventional counterpart. The Consultation concluded that the application of the concept of substantial equivalence contributes to a robust safety assessment framework. The Consultation was satisfied with the approach used to assess the safety of the genetically modified foods that have been approved for commercial use.

Similarly, in a May 2000 report, the Organization for Economic Cooperation and Development (OECD) examined the safety of novel foods and feeds. It concluded that:

> Safety assessment based on substantial equivalence is the most practical approach to address the safety of food and food components derived through modern biotechnology.

In its 1992 policy on foods derived from new plant varieties (FDA 1992), FDA employs the concept of substantial equivalence by focusing on the characteristics of the food product. Foremost, this policy on food products from new plant varieties is intended to be applied regardless of the derivation of the plant, i.e., through conventional breeding or rDNA biotechnology methods. FDA has identified certain characteristics of these foods that would

dictate the need for further scrutiny to establish safety. These include a substance that is completely new to the food supply, an allergen expressed in an unusual or unexpected circumstance, changes in the concentrations of major dietary nutrients, and increased concentrations of antinutritional factors and toxins inherent to the food. Although the FDA policy does not specifically use the term substantial equivalence, the absence of the characteristics mentioned above would lead to the conclusion that a food from a new plant variety is substantially equivalent to its traditional counterpart.

Safety of Introduced Genetic Material and Gene Product

Under FDA's current (1992) policy, as a starting point, the characteristics of the product are assessed, including the nucleotide sequence of the DNA of the genetic material that is used for plant transformation. This procedure provides important information on the encoded protein(s), regulatory elements controlling expression, and the presence or absence of additional potential coding sequences within the DNA. Although all extraneous non-coding DNA may not be identified, it can be minimized to very small segments. This level of detail cannot ordinarily be determined for new plant varieties produced in conventional ways such as hybridization.

Thus, the FDA policy contemplates that the structure and function of proteins encoded by the gene(s) introduced into plants will be understood in considerable detail. This information is used to assess the level of any potential risk, both of the introduced protein and of other products that may be produced or altered by the presence of the introduced protein. An additional factor is the source of the gene. The FDA policy contemplates that the following questions be addressed: Does the source organism have a history of safe use? and Does the source of the gene produce any endogenous toxins or allergens, that would need to be assessed in the genetically modified plant?

Any potential safety concerns associated with the source organism would serve to focus the safety assessment of the rDNA biotechnology-derived plant and the products derived from that plant. For example, if a gene were obtained from a source that produced a known allergen, the proteins encoded by the introduced DNA would have to be assessed to demonstrate that this DNA did not encode an allergen.

Safety of Introduced Genetic Material. The initial step in a safety assessment is full characterization of the genetic construct being inserted. This step includes identifying the source of the genetic material to establish whether it originates from a pathogenic, toxin-producing, or allergenic source. Parameters measured include the size of the genetic construct that is inserted into the plant genome, the number of constructs inserted, the location of insertion, and the identification of genetic sequences within the construct that allow for its detection (marker sequences) and expression (promoter sequences) in the plant.

The genetic material transferred is composed of DNA. All food, rDNA biotechnology-derived or otherwise, contains DNA. Individuals consume large quantities of DNA when eating conventional foods (Beever and Kemp, 2000). The DNA introduced using rDNA biotechnology represents only a tiny fraction of the total DNA consumed when the food is eaten, and transfer of genes from rDNA biotechnology-derived plants to mammalian cells is extremely unlikely.

Since DNA occurs in all foods, it is not subject to a safety evaluation (IFBC, 1990; Miraglia et al., 1998). It is well-established that DNA is rapidly digested in the gastrointestinal tract, and there is no evidence of DNA transfer from foods to human intestinal cells or gut microorganisms (Donaldson and May, 1999). Any plant DNA that might be found in human tissues is likely to be a small, non-functional fragment resulting from centuries of consumption and does not imply that plant foods are unsafe. Moreover, the likelihood of transfer of rDNA segments from foods produced using rDNA biotechnology is far less than for DNA from conventional foods simply because the novel DNA is less than 1/250,000 of the overall amount consumed (FAO/WHO, 2000).

Earlier rDNA biotechnology-derived foods were based on the use of selectable marker genes that confer resistance to an antibiotic. A workshop convened by the WHO concluded that the presence of marker genes per se in food would not constitute a safety concern (WHO, 1993). FAO/WHO (2000) recently reconsidered the issue of antibiotic resistance marker genes and again found there is no evidence that the markers currently in use pose a health risk to humans or domestic animals. Still, genes that confer resistance to drugs with specific medical use or limited alternative therapies should not be used in widely disseminated rDNA biotechnology-derived foods.

Following extensive examination, FDA decided to permit the use of kanamycin-resistance genes in the development of rDNA biotechnology-derived tomatoes, oilseed rape, and cotton for food and feed use and permitted these crops in food and feed (FDA, 1994). FDA concluded that the DNA for kanamycin resistance was not different from other rDNA in its digestibility and does not pose a food safety concern.

The marker gene used to confer kanamycin resistance was the neomycin phosphotransferase, type II gene (NPTII). The NPTII protein is rapidly degraded, like other dietary proteins, when subjected to conditions which simulate mammalian digestion. This protein has also been tested in acute toxicology studies at levels more than one million times the level that would be consumed by people eating food from rDNA biotechnology-derived plants. Finally, the transformation of intestinal bacteria by kanamycin resistance from plants is negligible, with a calculated theoretical maximum of less than 1 in 100,000 compared to bacterial transfers of resistance (WHO, 1993). Thus, this protein poses no food safety concerns. FDA concluded that there is no inherent danger presented by the presence of the antibiotic resistance markers used in earlier rDNA biotechnology-derived foods. These marker genes, such as the NPTII gene, do not present a food or feed safety concern and are not considered to be either toxic or allergenic.

The risk that the use of antibiotic resistance genes could lead to a transfer of antibiotic resistance and reduced efficacy of antibiotics is extremely small, because it would require a series of events, each of which is highly unlikely. Moreover, if such a move did occur, antibiotic selection would be needed to make the newly resistant strain a common one (Salyers, 2000). These concerns are addressed in additional detail in the *Benefits and Concerns* section.

Safety of Gene Product. FDA's 1992 policy also contemplates that, once the genetic construct has been fully characterized, an assessment of the safety of the gene product will be conducted. [The gene product is the protein, often an enzyme, that is produced by the newly introduced gene(s) and is present in the rDNA biotechnology-derived food or food ingredient, e.g., the protein expressed in Bt corn, encoded by genes from *Bacillus thuringlensis* (Bt), that confers pesticidal specificity for lepidopteran insects.] Safety evaluations typically include identification of the composition and structure of the gene product; a quantification of the amount of gene product expressed in the edible portion of the food; a search for similarity to known toxins and antinutritional factors, allergens, and other functional proteins; a determination of the thermal and digestive stability of the gene product; and the results of both in-vivo and in-vitro toxicological assays to demonstrate lack of apparent allergenicity or toxicity (Donaldson and May, 1999).

Unintended Effects

From a safety perspective, unintended effects of genetic modification have been speculated to manifest as the unintended expression of some unknown or unexpected toxic or antinutrient factor, or the otherwise unintended enhanced production of known toxic constituents (Royal Society, 1998).

However, based on the knowledge gained to date from the multitude of foods derived from rDNA biotechnology, there is no scientific evidence of the occurrence of such unintended effects. Given the more precise and predictable nature of genetic change accomplished through rDNA techniques as compared to the random genetic changes observed in conventional breeding, such unintended effects would be considered less likely in foods derived from rDNA biotechnology. Furthermore, these effects have been observed infrequently in the many thousands of crosses involving conventional crop breeding. In such cases, the source of the toxic constituent can typically be traced back to a related species used in conventional cross-breeding manipulations. For example, high glycoalkaloid concentrations were found in the conventionally bred Lenape potato, and the variety was subsequently withdrawn by the U.S. Department of Agriculture (Zitnak and Johnston, 1970). These toxins are present in all potatoes, and new potato cultivars are routinely screened for glycoalkaloid content. The unusually high glycoalkaloid content in Lenape was attributed to the use of the wild, non-tuber-bearing *Solanum chacoense* in its parentage. Interestingly, Lenape is a parent of Atlantic, a current potato variety with a glycoalkaloid content typical of the range for edible potatoes.

Allergenicity

Food allergies involve abnormal immunological responses to substances in foods, usually naturally occurring proteins found in commonly allergenic foods such as peanuts, milk, and seafood. Allergic reactions can be manifested by symptoms ranging

from mild cutaneous or gastrointestinal symptoms to life-threatening anaphylactic shock reactions. Virtually all food allergens are proteins, although only a small fraction of the proteins found in nature (and in foods) are allergenic. Since genetic modifications involve the introduction of new genes into the recipient plant and since these genes would produce new proteins in the improved variety, the potential allergenicity of the newly introduced protein should be a key component of the safety assessment process.

An assessment of the potential allergenicity of rDNA biotechnology-derived foods typically follows the decision-tree process outlined by the International Food Biotechnology Council (IFBC) and the Allergy and Immunology Institute of the International Life Sciences Institute (ILSI) (Metcalfe et al., 1996). This strategy focuses on specific scientific criteria, including the source of the gene(s), the sequence homology of the newly introduced protein(s) to known allergens, the immunochemical reactivity of the newly introduced protein(s) with immunoglobulin E (IgE) antibodies from the blood serum of individuals with known allergies to the source from which the genetic material was obtained, and the physicochemical properties, e.g., digestive stability, of the introduced protein.

At the recently concluded expert consultation (FAO/WHO, 2000), several other criteria, including the level of expression of the newly introduced protein(s) in the edible portions of the improved variety and the evaluation of the functional category for the introduced protein (some functional categories of proteins, e.g., high-methionine 2S albumins, are known to contain several allergens from different sources), were suggested for addition to the IFBC-ILSI allergenicity assessment strategy.

The first step of the allergenicity assessment (Fig. 1) involves the classification of the source of the genetic material as either commonly allergenic, less commonly allergenic, or of unknown allergenic potential. Eight foods or food groups, including milk, eggs, fish, crustacean shellfish, peanuts, soybeans, tree nuts, and wheat, are well accepted as commonly allergenic; these eight foods or food groups account for more than 90% of all food allergies in the world (FAO, 1995). More than 160 other foods have been described to cause allergic reactions (Hefle et al., 1996), and would be classified as less commonly allergenic. However, many of the genes that have been and will be used to produce rDNA biotechnology-derived foods are obtained from sources with no history of allergenicity as foods. Certainly, if the source contains well known environmental allergens, e.g., ragweed that contains common ragweed pollen allergens, then the allergenicity of newly introduced protein(s) from such sources must be carefully evaluated.

The approaches to allergenicity assessment vary according to the nature of the source of the transferred genetic material. If the genetic material is obtained from a known allergenic source, either commonly or less commonly allergenic, and the encoded protein is expressed in the edible portion of the rDNA biotechnology-derived food, then the protein must be considered to be an allergen unless proven otherwise.

In such situations, the next step in the allergenicity assessment is a determination of the immunoreactivity of the newly introduced protein with IgE antibodies from the sera of individuals allergic to the donor organism. The blood serum can be tested for reactivity with the purified protein or extracts of the genetically modified food using immunoassays (Yunginger and Adolphson, 1992; Taylor and Lehrer, 1996). If a sufficient number of test sera are used as advocated in the decision-tree approach (Metcalfe et al., 1996), the allergenicity of the introduced protein can be determined with a high degree of confidence. However, if negative results are obtained in the immunoassays, the rDNA biotechnology-derived food or extracts of that food should be tested further using in-vivo skin-prick tests (Bock et al., 1977; Taylor and Lehrer, 1996), double-blind, placebo-controlled food challenges (Bock et al., 1988; Taylor and Lehrer, 1996), or digestive stability assessments (Astwood et al., 1996) as advocated by the IFBC-ILSI decision tree. If the immunoassays and these other tests, as appropriate, are negative, then the likelihood that the rDNA biotechnology-derived food contains an allergen would be quite small.

The most difficult assessment occurs when genes are obtained from sources with no history of allergenicity, such as viruses, bacteria, or non-food plants. The likelihood that the proteins derived from such sources of DNA will be allergens is not very high, since most proteins in nature are not allergens (Taylor, 1997). Additionally, many of these proteins will be expressed in the rDNA biotechnology-derived food at very low levels, while allergic sensitization is more likely to occur to the major proteins that exist in foods (Taylor, 1997). The key features of the allergenicity assessment for such foods involve a

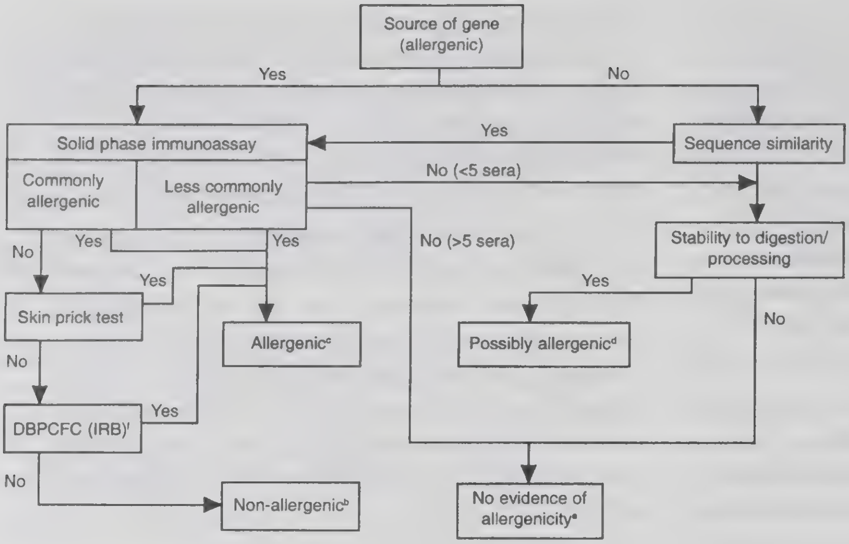

Fig. 1 ■ Assessment of the allergenic potential of foods derived from genetically modified crop plants[a].

[a] From FAO/WHO 2000. Adapted from decision-tree approach developed by International Food Biotechnology Council and Allergy and Immunology Institute of the International Life Sciences Institute (Metcalfe et al., 1996).

[b] The combination of tests involving allergic human subjects or blood serum from such subjects would provide a high level of confidence that no major allergens were transferred. The only remaining uncertainty would be the likelihood of a minor allergen affecting a small percentage of the population allergic to the source material.

[c] Any positive results obtained in tests involving allergic human subjects or blood serum from such subjects would provide a high level of confidence that the novel protein was a potential allergen. Foods containing such novel proteins would need to be labeled to protect allergic consumers.

[d] A novel protein with either no sequence similarity to known allergens or derived from a less commonly allergenic source with no evidence of binding to IgE from the blood serum of a few allergic individuals (<5) but that is stable to digestion and processing should be considered a possible allergen. Further evaluation would be necessary to address this uncertainty. The nature of the tests would be determined on a case-by-case basis.

[e] A novel protein with no sequence similarity to known allergens and that was not stable to digestion and processing would have no evidence of allergenicity. Similarly, a novel protein expressed by a gene obtained from a less commonly allergenic source and demonstrated to have no binding with IgE from the blood serum of a small number of allergic individuals (>5 but <14) provides no evidence of allergenicity. Stability testing may be included in these cases. However, the level of confidence based on only two decision criteria is modest. The FAO/WHO Expert Consultation suggested that other criteria should also be considered, such as the level of expression of the novel protein.

[f] Double-blind placebo-controlled food challenge (institutional review board).

comparison of the amino acid sequence of the introduced protein with the amino acid sequences of known allergens and the digestive stability of the introduced protein. While the combination of these two criteria provides reasonable assurance that the introduced protein has limited allergenic potential, the ideal approaches to the application of these two criteria have been debated, and the desirability of adding other criteria for the allergenicity assessment of such products has been advocated (Wal, 1998).

The criterion of amino acid sequence homology to known allergens is a logical and increasingly powerful approach. The amino acid sequences of more than 300 known allergens are available for comparative purposes. The IFBC-ILSI strategy defines significant sequence similarity as a match of at least eight contiguous, identical amino acids based on the minimal peptide length needed for T-cell binding, which is a necessary prelude to allergic sensitization; this approach is clearly limited in that it cannot identify discontinuous or conformational epitopes that are dependent on the tertiary structure of the protein (Metcalfe et al., 1996). Others have suggested that the definition of significant sequence homology be modified to a minimal peptide length of less than eight contiguous, identical amino acids (Consumer and Biotechnology Foundation, 1999). While this criterion (amino acid sequence homology to known allergens) is clearly useful, international agreement must be sought on Its application.

Known food allergens tend to be quite stable to digestive proteases (Astwood et al., 1996) with the exception of the pollen-related food proteins that cause oral allergy syndrome (Taylor and Lehrer, 1996). Thus, digestive stability can be used as a criterion for the assessment of the allergenic potential of the introduced proteins. Both simulated gastric and intestinal models of mammalian digestion are advocated for such assessments (Astwood et a)., 1996; Metcalfe et a)., 1996). While the usefulness of this criterion is apparent, consensus is needed on the ideal protocols for assessment of digestive stability. It is recognized that novel proteins may exist that are stable to digestion but will not become allergens. Additional testing is needed to assess the allergenic potential of such proteins (FAO/WHO, 2000).

The development of additional criteria and additional tests to use in the assessment of the allergenicity of rDNA biotechnology-derived foods would be advantageous in cases where the gene is obtained from sources with no history of allergenicity. As mentioned, the level of expression of the

introduced protein and the functional category of the introduced protein could be used as additional criteria (FAO/ WHO, 2000). In addition, the development of suitable animal models for the prediction of the allergenic potential of the introduced proteins is anticipated in the future. While several animal models appear to be promising (Knippels et al., 1998), none has been sufficiently validated for its routine use in the assessment of the allergenicity of rDNA biotechnology-derived foods.

The existing decision-tree approach has already been applied in the assessment of the allergenicity of rDNA biotechnology-derived foods. The enzyme introduced into glyphosate-tolerant soybeans has no sequence homology to known allergens and is rapidly digested in simulated mammalian digestion systems (Harrison et al., 1996). Similarly, several of the Bt proteins used in insect-resistant crops and the proteins produced by common marker genes are rapidly digested in simulated mammalian digestion systems (Astwood et al., 1996). A high-methionine protein introduced into soybeans by the transfer of a gene from Brazil nuts to correct the inherent methionine deficiency in soybeans was shown to bind to IgE from the sera of Brazil nut-allergic individuals and to elicit positive skin-prick tests in some of these patients (Nordlee et al., 1996). This protein was thus identified as the major allergen from Brazil nuts that had not previously been characterized. As a result, commercial development of this particular soybean variety was discontinued.

Clearly, the assessment of the allergenicity of rDNA biotechnology-derived foods should be a key component of the overall safety assessment process in all cases. A useful strategy has been developed for such assessments, although this strategy should be viewed as dynamic and new approaches and criteria should be added once they are validated and accepted.

Products without Conventional Counterparts

Recombinant DNA-derived biotechnology foods without conventional counterparts need to be evaluated on a case-by-case basis and would be subject to some types of toxicity assessments, depending on the nature of the modification (IFBC, 1990). This situation has not yet arisen with rDNA biotechnology derived foods, although at some point it undoubtedly will. When it does, the situation will raise a variety of issues that will need to be addressed in a scientifically based, flexible manner.

Whole foods are complex mixtures of chemical components characterized by wide variations in composition and nutritional qualities, and are not well suited for traditional toxicological studies designed to assess individual chemical entities. The testing of whole foods—rDNA biotechnology-derived or conventional—in animal feeding studies, for example, is limited by factors such as the animal's qualitative and quantitative feeding preferences and the levels of nutritional and antinutritional factors and other substances that are present. When one researcher attempted to ascertain the toxic threshold for an rDNA biotechnology-derived tomato by feeding rats freeze-dried tomato extract, the experiments were limited to the human equivalent of 13 tomatoes a day by negative effects of inorganic compounds, such as potassium, that are present in rDNA biotechnology-derived and conventional tomatoes alike. But, as noted by MacKenzie (1999), "Toxicologists still said we hadn't fed them enough to get a meaningful result."

Another limitation is that animal toxicity tests are seldom sufficiently sensitive to distinguish differences between the toxicity of a new variety and its conventional counterparts. Indeed, most foods will produce adverse effects in long-term animal feeding studies when fed in high proportions of the diet, regardless of the nature of production. The results of such studies are not easily interpreted, and apparent adverse effects are often the indirect effects of related nutritional dietary imbalance, rather than any specific compound in question. OECD (2000) recognized that there is no scientific justification for requiring long-term feeding studies for rDNA biotechnology-derived foods, and that such studies would be unlikely to provide meaningful information in the great majority of cases. FAO/WHO (2000) concurred, finding that the practical difficulties in the application of conventional toxicology studies to whole foods preclude their use as a routine safety assessment technique.

The key differences between the testing of whole foods and the testing of individual chemical substances in animal feeding studies are indicated in Table 1.

Thus, given a hypothetical rDNA biotechnology-derived food without a conventionally derived counterpart, animal studies would need to be designed to address specific nutritional or toxicological concerns. However, these studies would need to be carefully designed to avoid or minimize the limitations discussed above that are associated with

Table 1 ■ Differences between animal testing of individual chemicals and whole foods[1].

Individual chemical testing	Whole foods testing
Typically a single, chemically identified substance	A complex mixture of many substances, most unidentified
Highest dose level should produce an adverse effect attributable only to the chemical	Highest dose that does not cause rejection of the diet, or nutritional imbalance, very unlikely to produce any toxic effect
Low doses, usually <1% of the diet	High doses, usually >10% of the diet
Easy to give a dose high enough to assure an adequate safety factor (>100x normal human intake)	Difficult or impossible to achieve doses more than a few multiples of human intake; therefore, no adequate safety factor
Acute effects obvious	Acute effects, other than nutritional imbalance, nearly always absent
Nutritional effects generally absent	Nutritional effects typically present
Specific routes of metabolism capable of being studied and ascertained	Complex metabolism of many ingredients, most unidentified; therefore, impossible to determine
Cause/effect relatively clear	Effects usually absent or, if observed, confused by multiple possible causes

[1] Based on Munro et a. (1986) and Hall (1981)

the testing of whole foods or major food constituents (Munro et al., 1996). For example, toxicological studies could be used to examine the potential for acute, chronic, carcinogenic, genotoxic, reproductive, and teratogenic effects of components or fractions of concern in a food derived from a new plant variety. A complete assessment would also include pharmacokinetic data regarding absorption, distribution, metabolism, and excretion of the new product or a novel component thereof. By focusing toxicological examination on carefully selected fractions or components of a food derived from a new plant variety, and excluding major components of no concern, it may be possible to reduce or eliminate the difficulties associated with testing whole foods.

The assessment of macronutrient substitutes or other major food constituents should follow a tiered approach (Munro et al., 1996), whereby the physical and chemical properties of the constituent are determined, in addition to its potential to disrupt or alter nutrient uptake. Initial predictive effect studies would dictate the physiologically relevant endpoint determinants of subsequent in-vitro and in-vivo studies (Munro et al., 1996). Further, the choice of animal model for any such in-vivo studies would have to be carefully considered for relevance when applying results to humans (Battershill et al., 1999).

Without precedence, the above discussion outlines a proposal which seems best calculated to provide the data needed for a persuasive showing of safety. Clearly, such novel foods without conventional counterparts, when they do become available, will need careful testing, evaluation, and regulatory scrutiny using a flexible process that contains case-by-case adaptation based on the novel nature of the issues presented.

Scientific Consensus About Safety

The Human Food Safety Panel reviewed available information about the safety of rDNA biotechnology-derived foods and found that there is striking congruence in the conclusions and recommendations of various international scientific groups that have considered the issue.

The National Academy of Sciences published a white paper (NAS, 1987) on the planned introduction of organisms derived using rDNA biotechnology into the environment. This white paper has had wide-ranging impacts in the United States and other countries. Its most significant conclusions and recommendations include (1) there is no evidence of the existence of unique hazards, either in the use of rDNA biotechnology techniques or in the move-

ment of genes between unrelated organisms, and (2) the risks associated with the introduction of rDNA biotechnology-derived organisms are the same in kind as those associated with the introduction of unmodified organisms and organisms modified by other methods.

In a 1989 extension of this white paper, the National Research Council (NRC), the research arm of the NAS, concluded that "no conceptual distinction exists between genetic modification of plants and microorganisms by classical methods or by molecular techniques that modify DNA and transfer genes" (NRC, 1989). The NRC report supported this statement with extensive observations of past experience with plant breeding, introduction of rDNA biotechnology-derived plants, and introduction of rDNA biotechnology-derived microorganisms:

> The committees [of experts commissioned by NRC) were guided by the conclusion (NAS, 1987) that the *product* of genetic modification and selection should be the primary focus for making decisions about the environmental introduction of a plant or microorganism and not the *process* by which the products were obtained.
>
> Information about the process used to produce a genetically modified organism is important in understanding the characteristics of the product. However, the nature of the process is not a useful criterion for determining whether the product requires less or more oversight.
>
> The same physical and biological laws govern the response of organisms modified by modern molecular and cellular methods and those produced by classical methods.
>
> Recombinant DNA methodology makes it possible to introduce pieces of DNA, consisting of either single or multiple genes, that can be defined in function and even in nucleotide sequence. With classical techniques of gene transfer, a variable number of genes can be transferred, the number depending on the mechanism of transfer; but predicting the precise number or the traits that have been transferred is difficult, and we cannot always predict the phenotypic expression that will result. With organisms modified by molecular methods, we are in a better, if not perfect, position to predict the phenotypic expression.
>
> Crops modified by molecular and cellular methods should pose risks no different from those modified by classical genetic methods for similar traits. As the molecular methods are more specific, users of these methods will be more certain about the traits they introduce into the plants.
>
> The types of modifications that have been seen or anticipated with molecular techniques are similar to those that have been produced with classical techniques. No new or inherently different hazards are associated with the molecular techniques.

The same principles were emphasized in a comprehensive report (NIH, 1992) by the U.S. National Biotechnology Policy Board, which was established by Congress and composed of representatives from the public and private sectors:

> The risks associated with biotechnology are not unique, and tend to be associated with particular products and their applications, not with the production process or the technology per se. In fact biotechnology processes tend to reduce risks because they are more precise and predictable. The health and environmental risks of not pursuing biotechnology-based solutions to the nation's problems are likely to be greater than the risks of going forward.

These findings are consistent with the observations and recommendations of the United Kingdom's House of Lords Select Committee on Science and Technology (UK,1993), which was very critical of that nation's policy of subjecting rDNA biotechnology-derived products to additional regulatory requirements:

> As a matter of principle, GMO-derived products [i.e., those from genetically manipulated organisms, or recombinant organisms] should be regulated according to the same criteria as any other product. . . . U.K. regulation of the new biotechnology of genetic modification is excessively precautionary, obsolescent, and unscientific. The resulting bureaucracy, cost, and delay impose an unnecessary burden to academic researchers and industry alike.

Three joint FAO/WHO consultations, addressing specifically the question of the safety of rDNA biotechnology-derived foods, came to similar conclusions. The first of these expert consultations (FAO/ WHO, 1991) concluded:

> Biotechnology has a long history of use in food production and processing. It represents a continuum embracing both traditional breeding techniques and the latest techniques based on

molecular biology. The newer biotechnological techniques, in particular, open up very great possibilities of rapidly improving the quantity and quality of food available. The use of these techniques does not result in food which is inherently less safe than that produced by conventional ones.

The second consultation (FAO/WHO, 1996) reaffirmed the conclusions and recommendations of the first FAO/WHO consultation:

> Food safety considerations regarding organisms produced by techniques that change the heritable traits of an organism, such as rDNA technology, are basically of the same nature as those that might arise from other ways of altering the genome of an organism, such as conventional breeding. . . . While there may be limitations to the application of the substantial equivalence approach to safety assessment, this approach provides equal or increased assurance of the safety of food products derived from genetically modified organisms as compared to foods or food components derived by conventional methods.

The most recent consultation (FAO/ WHO 2000) examined the evidence to date and concluded:

> A comparative approach focusing on the determination of similarities and differences between the genetically modified food and its conventional counterpart aids in the identification of potential safety and nutritional issues and is considered the most appropriate strategy. . . . The Consultation was of the view that there were presently no alternative strategies that would provide better assurance of safety for genetically modified foods than the appropriate use of the concept of substantial equivalence.

OECD (1993) offered several conclusions and recommendations that are wholly consistent with the NAS, NRC, and FAO/WHO findings:

> In principle, food has been presumed to be safe unless a significant hazard was identified.
>
> Modern biotechnology broadens the scope of the genetic changes that can be made in food organisms and broadens the scope of possible sources of foods. This does not inherently lead to foods that are less safe than those developed by conventional techniques.
>
> Therefore, evaluation of foods and food components obtained from organisms developed by the application of the newer techniques does not necessitate a fundamental change in established principles, nor does it require a different standard of safety.
>
> For foods and food components from organisms developed by the application of modern biotechnology, the most practical approach to the determination of safety is to consider whether they are *substantially equivalent* to analogous conventional food product(s), if such exist.

OECD (1998) reaffirmed the conclusions and recommendations of previous consultations of both FAO/WHO and OECD. Regarding the specific question of potential allergenicity of novel proteins introduced in rDNA biotechnology-derived foods, the report stated:

> While no specific methods can be used for proteins derived from sources with no history of allergy, a combination of genetic and physicochemical comparisons exist which can be used as a screen. The application of such a strategy can provide appropriate assurance that foods derived from genetically modified products can be introduced with confidence comparable to other new plant varieties.

In 2000, OECD acknowledged the public concerns about the safety assessment of rDNA technology (OECD 2000), stating:

> Although [the] food safety assessment is based on sound science, there is a clear need for increased transparency and for safety assessors to communicate better with the public. Much progress has already been made in this regard. . . . However, more could be done in this area.

The NRC's Committee on Genetically Modified Pest-Protected Plants published a report (NRC, 2000) that reaffirmed the principles set forth in the 1987 NAS white paper. Specifically, the committee found that "there is no strict dichotomy between, or new categories of, the health and environmental risks that might be posed by transgenic and conventional pest-protected plants" and that the "properties of a genetically modified organism should be the focus of risk assessments, not the process by which it was produced." The committee concluded that "[w]ith careful planning and appropriate regulatory oversight, commercial cultivation of transgenic pest-protected plants is not generally expected to pose higher risks and may pose less risk than other commonly used chemical and biological pest-management techniques." (While the report focused on rDNA biotechnology-derived pest-protected plants, the committee stated that many of its

conclusions are also applicable to rDNA biotechnology-derived plants generally.)

In summary, the safety of rDNA biotechnology-derived foods has been extensively reviewed by a number of scientific organizations, at the national and international level. The use of rDNA biotechnology in itself has no impact on the safety of such foods. Foods derived using rDNA biotechnology are subject to rigorous and systematic scientific evaluations under existing principles of food safety-far more than are routinely applied to the products of traditional breeding. Thus, the level of field testing and premarket review for food safety provide assurance that foods derived from plants and microorganisms through rDNA biotechnology are at least as safe as existing foods, and are consistent with all existing standards of food safety.

Conclusions

Based on its evaluation of the available scientific evidence, the Human Food Safety Panel reached the following conclusions:

- Biotechnology, broadly defined, has a long history of use in food production and processing. It represents a continuum that encompasses both centuries-old traditional breeding techniques and the latest techniques based on molecular modification of genetic material, which are a major step forward by virtue of their precision and reach. The newer rDNA biotechnology techniques, in particular, offer the potential to rapidly and precisely improve the quantity and quality of food available.
- Crops modified by modern molecular and cellular methods pose risks no different from those modified by earlier genetic methods for similar traits. Because the molecular methods are more specific, users of these methods will be more certain about the traits they introduce into the plants.
- The evaluation of food, food ingredients, and animal feed obtained from organisms developed with the newer rDNA biotechnology techniques of genetic manipulation does not require a fundamental change in established principles of food safety; nor does it require a different standard of safety, even though, in fact, more information and a higher standard of safety are being required.
- The science that underlies rDNA biotechnology-derived foods does not support more stringent safety standards than those that apply to conventional foods.
- The use of rDNA biotechnology and molecular techniques of genetic manipulation significantly broadens the scope of the genetic changes that can be made in food organisms and broadens the scope of possible sources of foods, but this does not inherently lead to foods that are less safe than those developed by conventional techniques. By virtue of their greater precision, such products can be expected to be better characterized, leading to more predictability and a more reliable safety assessment process.

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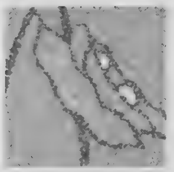

Constructing Markets for GMO Crops: Responding to Consumer and Public Interest

Randall Westgren

The development of new applications of biotechnology has been hailed for a decade as a new "post-industrial" revolution. We are now at the beginning of the commercialization of biotechnologies in the agricultural sector and the revolution has slipped into trench warfare on some fronts; market acceptance is not universal. Traditional supply chains were envisioned for distribution of input trait-modified corn and soybean because these varieties do not affect value to the end user and therefore are not physically differentiable from nonmodified varieties. However, with the recent development of international concerns about the basic technologies of genetic modification (particularly in Europe, but also extending to Japan and other countries), some or all types of genetically modified grain and oilseeds may need to be segregated from nonmodified crops.

The short-term impact of this international resistance to genetic modification is primarily confusion across the marketplace, as firms in the supply chain try to identify which of their customers require nongenetically modified corn and soybean, to identify how they can be segregated throughout the supply chain, and to evaluate whether existing testing technologies can ascertain whether corn and soybean they receive are genetically modified. There are many unresolved issues in the transactions between firms in the production and marketing of genetically modified organisms (GMOs). There are several valid questions associated with these issues. Is there a need for pricing differentials (i.e., premiums and discounts), and should nongenetically modified crops command a higher price? What is the liability for delivering contaminated (mixed) loads and can one be insured against this liability? How will technologies for sampling and testing, segregation requirements, and labeling be introduced into the market—as mandatory or voluntary programs?

Social Construction of Markets between Buyers and Sellers

All of the problems that surround the commercialization of genetically modified crops are symptoms of the early stages of a process called the social construction of the market. All markets are social constructions. That is, they evolve from a series of exchanges between buyers and sellers, during which the attributes of products are defined, agreed to, and revised over time. Even markets that we take for granted such as the corn market and the PC market were socially constructed in the past. The modern corn market evolved 150 years ago when forward contracts in Chicago developed to manage inventories and seasonal prices (Hieronymus 1971) and many of the commercially relevant product attributes were codified under the Grain Standards Act of 1916. The PC market evolved before our eyes in the last 2 decades. Most people have shared understanding of what a personal computer is and what its important components—monitor, keyboard, hard drive, modem—are when they enter the market to make a purchase.

Social construction is a messy process. Think of how the debate over defining test weight for a bushel of corn and establishing the thresholds for moisture and damage for different grades must have played out in active discourse among merchandisers,

processors, regulators, and farm groups. Think of how much easier it is now to specify computer components given common standards for interfaces, baud rates for modems, and storage media, compared with standards in the early 1980s.

Social construction of markets in agriculture is more complex than in many other sectors of the economy. The supply chain between input suppliers and the consumer is long and has many market links. In a stylized supply chain for genetically modified corn, we may count eight distinct market links: genetics company to seed company, seed company to producer, producer to country elevator, country elevator to processor, processor to food manufacturer, food manufacturer to wholesaler, wholesaler to retailer, and retailer to consumer. Some supply chains have more links, others have fewer. However, it is hard to find another sector of the economy where the consumer is farther away from the basic technologies than in agriculture. For this reason, the commodity market has served the crop supply chain well. Homogeneous products with well-understood attributes could pass easily along the supply chain in efficient, large-scale transactions. The hundreds of hybrids and varieties of grains and oilseeds could be commingled in the homogeneous market channels.

It was presumed that this efficient market system would easily accommodate input trait-modified crops such as Roundup Ready soybean and *Bacillus thuringiensis* (Bt) corn. They are effectively homologous to nonmodified hybrids and varieties in processing and end use. Or are they? This issue is where the social construction process for input trait-modified crops has foundered. There are two separate forces at work in the current debate over how the socially constructed market for GMO foods will evolve. One force is at the downstream end of the supply chain. Consumers and retailers, acting on behalf of concerned consumers, have not agreed to the equivalence of GMO varieties. In large part, this disagreement is a result of how they view risks of biotechnology in the food supply. The other force is a broader social movement of public interest groups, regulators, and other social agents that have similar, but not identical, concerns about biotechnology. This phenomenon is called the social embeddedness of the GMO market; in addition to the process by which buyers and sellers construct markets as part of the normal course of business, there is a legitimation process by which society determines whether any institution or technology conforms to social and regulatory norms. Is this the "right" kind of product or technology?[1]

Consumer Interest and Risk Perceptions

One of the great frustrations of persons promoting the adoption of biotechnology in agriculture is that consumers do not behave rationally with regard to the low-level hazards inherent in the new products (Wolt and Peterson 2000). Consumers respond emotively to hazards and discount scientific assessments and arguments. This behavior is by no means new. The same behavior was seen with respect to nuclear power, hazardous waste storage siting, pesticides, and other technologies or hazards that have been part of public discourse for decades.

Wolt and Peterson (2000) recount the history of risk analysis as part of the public interest and regulation of environmental hazards. Risk analysis became formalized in the 1980s beginning with the development of scientific risk assessment procedures under the National Research Council. A political–social component became a necessary adjunct to scientific assessments as governments dealt with the complex social process of getting from risk assessment to the promulgation of regulations.

One of the most interesting developments of the 1980s was a seminal study by Slovic et al. (1985). They developed a multidimensional scale to which consumers responded about the nature of risks they perceived, not just the level of perceived hazard. The dimensions of risks are as follows[2]:

1. Voluntariness of risk—do people face this risk voluntarily or is it thrust upon them?
2. Immediacy of risk—are the consequences immediate or do they occur much later?
3. Knowledge about the risk—is the risk (level) known by science at the time of exposure?

[1] Illinois residents are familiar with a similar legitimacy debate: the continued use of Chief Illiniwek as a symbol associated with the University of Illinois. In the same way that public interest and pressure groups have made it difficult for the University community to treat the question as an internal one, public interest groups make it difficult for biotech companies, farmers, and grain merchandisers to adopt genetically modified crops as a private business decision.

[2] The last four dimensions are added to the original list by Sandman (1986) as part of a project of the Environmental Communication Research Program at Rutgers University.

4. Knowledge about the risk—do people know the level of risk?
5. Control over risk—do people have control over the consequences of exposure?
6. Newness—is this a novel or a familiar source of risk?
7. Chronic consequence—are the consequences slow and chronic or acute and catastrophic?
8. Dread—is this a risk that can be faced objectively or does it evoke feelings of dread?
9. Natural—is the source of risk naturally occurring or artificial?
10. Diffused—is the consequence diffused over time/space or highly localized?
11. Fair—is the risk fairly distributed or unfairly distributed (targeted)?

To the extent that consumers feel that risks are more voluntary, more immediate, controllable, familiar, fair, chronic, natural, diffused, and fair; and to the extent that scientific and lay knowledge is available; and to the extent that the risk is not suffused with dread, they will be more accepting of the risks. They also tend to underestimate the actual level of risk. To the extent the opposite conditions occur, consumers vastly overestimate the risk. In addition, Hance et al. (1991) say that consumers faced with dread, unfair, acute, uncontrollable, artificial, involuntary, and catastrophic risk react with "moral outrage"—a strong emotional response that dwarfs their perceptions of the level of risk they perceive.

A couple of examples should elucidate these points. The public outcry that caused the withdrawal of Alar from use as a growth regulator for apples was driven by moral outrage rather than the low levels of scientific risk. The risk was unfair; children had disproportionate exposure. The risk was unnatural; apple growers were "messing with Mother Nature" in applying Alar to an icon of "naturalness." To a lesser degree, Alar was perceived as uncontrollable and involuntary. Consumers had this risk forced upon them by common practice in the agricultural sector.

A second example was the outbreak of bovine spongiform encephalopathy (BSE), or mad cow disease, in Europe. The risk was unknown (or perhaps, unknowable) in that the scientific community denied the possibility that the prions that caused scrapie in sheep could cross the species boundary into cattle and later cross the species boundary into humans as Creutzfeldt-Jakob disease. (See the University of Illinois at Urbana-Champaign research project Web site on BSE at http://w3.aces.uiuc.edu/AnSci/BSE/). In addition, the disease was involuntary, uncontrollable, unfair, unfamiliar, acute, focused, and most especially, dread. Could any risk have a higher moral outrage quotient than one in which a common foodstuff, hamburgers, causes horrible neurological damage, debility, and death?

Clearly, the allergenicity risk associated with StarLink-treated corn hybrids is not of the same magnitude as the risk associated with BSE exposure. However, the decisions to remove StarLink corn from commercial channels to avoid further contamination of the food supply, and to withdraw StarLink from the market until regulatory approval for food use is granted, are necessary. Given that food use approval has not been granted and that studies on allergenicity are not yet part of the public record, it would be futile for Aventis to try to fight this out in the court of public opinion. In addition, it boots nothing to appeal to fairness and familiarity of food allergens to make the case that allergenicity from foods made from StarLink corn hybrids is not a real risk to consumers. In the quote below, taken from the Aventis Web site (http://www.us.cropscience.aventis.com/AventisUS/CropScience/stage/html/allergen1.htm), the company makes a common error in risk communication to consumers:

> Although the term 'food allergy' is widely used for any adverse reaction to food, only rarely is the immune system involved. The most common adverse reactions to food are toxic reactions and food intolerance. Natural foods, not additives or artificial flavors, are the basis for the majority of food allergies. Any food that contains proteins (i.e. the vast majority) has the potential to cause allergenic reactions in some people. Natural proteins in peanuts, cow's milk, eggs, wheat, soybean, tree nuts, fish and shellfish cause 90% of all food allergens.

Because any potential allergenicity arising from genetically modified corn is not natural, consumers react negatively to the assertion that the risk is no different than from naturally occurring proteins. And if the product is not labeled so that consumers can take the risk voluntarily, they react with moral outrage, even if the risk is statistically small. Hance et al. (1991) make two points about communicating risks to the public: 1) avoid comparisons that ignore

the "outrage" factors, and 2) avoid comparisons that seem to minimize or trivialize risk. If one tries to reassure consumers about a GMO-borne risk, don't say that the risk is no greater than from naturally occurring risks (e.g., cancer from suntanning or eating peanut butter) or from equally likely, but unrelated, hazards (e.g., death from falling off playground equipment).

A supply chain that is set up for success has full, open communication that presents the risks openly. The outrage factors are limited. To the extent possible, the presentation should describe the risk as fair, familiar, controllable, natural, and voluntary. Recent experience in the United States with BST milk is a good example. Runge and Jackson (2000) showed that the use of "negative" labels allowed for 1) the development of a niche market for non-GMO milk and 2) enough reassurance for consumers that aggregate milk consumption was unaffected by the GMO controversy. The negative labels stated "Milk from cows not treated with rBST." In addition, the labels said, "The federal government has determined that rBST milk is safe for humans and cows, and that no significant difference has been shown between milk from rBST treated or non-rBST treated cows." Consumers drew assurance from the stated facts, their perception that the government was exercising necessary oversight, and their ability to make a voluntary decision in the marketplace.

The Broader Public Interest in the GMO Market

The acceptance of a new technology and the way it is brought to market require that society gives a normative "blessing" beyond accepting the practical, pragmatic value of the technology. This phenomenon is called the embeddedness of the market (Granovetter 1985), and is partly due to general unease with new technology in society, a phenomenon described by Collins and Pinch (1998). Their book, *The Golem at Large: What You Should Know about Technology*, is a series of case studies that show technology as a product of social activity, not perfect applied science. The Golem is a creature from Jewish mythology, which, although not evil, is powerful and clumsy, and therefore potentially dangerous. Even well-designed products, based on sound technologies, must pass muster with the broad public interest.

Bender and Westgren (2001) examine the embeddedness phenomenon for the social construction of a market for genetically modified soybean. They highlight the conflict that exists between the industry's interest in the existing, institutionalized commodity market as a vehicle for commercializing GMO crops and the public interest in identity preservation and segregation of GMOs. The commodity market is well understood and many of the social groups involved in domestic and international commerce in soybean have a stake in it as an efficient, high-volume market channel. On the other hand, a world where all GMO attributes must be segregated implies the development of many small-volume, specialized market channels. When output trait crops become common (e.g., new amino acid profiles in corn and soybean) the number of segregated markets will burgeon.

The pathway towards a social construction of the market(s) will be chosen in a complex process that balances the structural inertia of the commodity market among merchants and U.S. producers of grains and oilseeds with the political and cultural embeddedness in the social discourse of governments, scientists, consumers, and environmentalists. For example, if substantive equivalence is granted between genetically modified and nonmodified varieties, then a grain market driven by homogeneity—the commodity market—can exist. To the extent that some jurisdictions require identification and labeling of food containing genetically modified organisms, the commodity market offers a single solution: all crops must be considered as genetically modified. Otherwise, the supply chain must develop a system of physical separation, oversight and testing, and regulation that creates separate markets for separate socially constructed products: genetically modified grains and nongenetically modified grains.

For some end-use consumers this is the minimal requirement to establish social legitimacy, which may be augmented by government regulation. For other end-use consumers, the separation of modified and nonmodified sources of corn and soybean may be unnecessary and artificial; their tolerance for commingling may be effectively unlimited. Nonetheless, if labeling and segregation are required by enough end-users in enough jurisdictions, we will likely see the development of parallel supply chains.

The social construction of genetically modified organisms and of the marketplace for delivering

them to buyers are contemporaneous phenomena. The codification of the technologies, i.e., what is acceptable to consumers and governments, and the construction of the markets are proceeding together. We are still a long way from resolving the conflicts that have stalled the commercialization of GMOs in the crop sector. We must address the idiosyncratic risk perceptions of consumers, so that they become willing, positive influences on the eventual acceptance of GMOs. To the extent we can limit their perceived risk exposure to biotechnology in the food supply by doing better risk communication and offering choices (i.e., voluntary labeling) that give them control, consumer interest will become more aligned with producers' interests. We will have to separate consumer interest from the broader public interest, so that the most volatile rhetoric around GMOs is defused.

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Handling of GM Crops Issues by the Mass Media

Eric A. Abbott, Tracy Lucht, Jeffrey P. Jensen, and Zajira Jordan-Conde

A content analysis was conducted of the coverage of genetically modified (GM) crops (genetically modified organisms, foods, research, etc.) from 1997 to 2000 in three major newspapers—the *New York Times* in the United States, and the *Times of London* and *Daily Mail* from Britain. For each newspaper, a Lexis-Nexis full-text search was conducted to identify all articles with relevant key words. A random sample of approximately 200 articles from each newspaper was then drawn representing four subperiods, and each article was analyzed for the presence of certain themes (human health, environment, business, farmers, moral, regulatory, labeling), whether the information was positive or negative, and which sources were quoted or referenced in the articles. Intercoder reliability for the samples was 0.85.

Previous studies (Priest 1995, Gaskell et al. 1999) found that during the early 1990s, coverage of agricultural biotechnology in Britain and the United States was overwhelmingly positive in tone, with scientists and industry representatives used most often as sources. However, a number of studies (Abbott and Yarbrough 1989,[1] Rogers et al. 1991, Abbott and Eichmeier 1998,[2] Abbott and Lucht 2000[3]) have found that a triggering event or "hoopla" can lead to a large increase in the volume of coverage—an increase that is associated with a change in tone as well as a change in the sources quoted in mass media. Our study examined changes in topic, tone, and sources about GM crops across these triggering or hoopla periods.

One general expectation of the research was that GM crops have moved from being a **scientific issue** with discussion mainly about technical issues conducted via journal articles, newspapers, and conferences, to a **social issue**, with discussion covering a much wider range of issues (morality, economics, politics, etc.) conducted by a variety of sources, including clergy, princes, politicians, activist groups, citizens, farmers, and shopkeepers. One result of becoming a social issue is that themes within articles are "framed" in moral, economic, or political terms rather than in scientific terms. Mass media and various interest groups may serve as "amplification stations" (Kasperson 1992, Hoban 1995)—entities that under certain circumstances focus their attention and resources on these issues. Neuman (1990) has noted that some triggering events—when newspaper coverage of an issue reaches somewhere in the range of 50–150 articles per month—can cause the issue to take off in the

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[2] Abbott, E.A., and A.A. Eichmeier. 1998, August 7. The hoopla effect: Toward a theory of regular patterns of mass media coverage of innovations. Paper presented to Theory and Methodology Division, Associate for Education in Journalism and Mass Communication, Baltimore.

[3] Abbott, E.A., and T. Lucht. 2000, July. How triggering events affect mass media coverage and source use concerning genetically modified organisms (GMOs) in Britain and the United States. Paper presented to Agricultural Communicators in Education, U.S. Agricultural 2000 Congress, Washington, DC.

eyes of the public, and begin to become "one of the most important" news topics.

In our study of coverage of GM issues in Britain and the United States, the articles were divided into four time periods:

1. a "pre-hoopla" period in which coverage was at a low level;
2. a "first hoopla" period, when there was a rapid increase in coverage. In Britain, this occurred in December 1998, when a scientific journal published news of a study showing negative effects from rats eating raw *Bacillus thuringiensis* (Bt) potatoes. In the United States, the first hoopla occurred in May 1999, when a scientific journal reported on a Cornell University study showing monarch larvae might be harmed by eating milkweed plants dusted with Bt corn pollen;
3. a "post-hoopla" period, when coverage declined; and
4. a "second hoopla" period, with another increase in coverage. In Britain, this second increase coincided with revelations that rapeseed imported from Canada and planted in 75 locations in Europe had been inadvertently crossed with a Bt variety. Coverage in the United States also increased at this time, focusing on both human health and environmental topics.

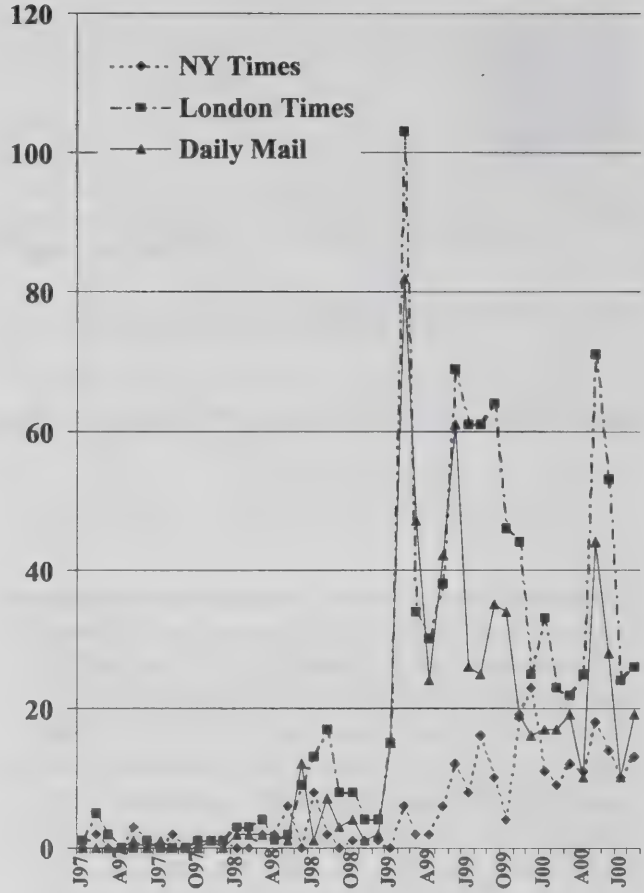

Figure 1 ■ **Total number of articles concerning GM foods and similar topics in three newspapers: *New York Times*, *Times of London*, and *Daily Mail*, 1997–2000.**

Results

Figure 1 shows the unevenness of coverage of GM crops over time in the three newspapers. In Britain, coverage in the *Times of London* and *Daily Mail* neared or exceeded 100 articles per month (approximately 3.5 stories per day) at the end of 1998 and beginning of 1999—a sufficient level of coverage to cause widespread public awareness of the issue and a subsequent hardening of positions. In the United States, the peak coverage occurred in May 1999, with 23 articles. The failure of U.S. coverage to reach Neuman's (1990) threshold explains, in part, why most people in the United States are not yet very knowledgeable about this issue. However, issues such as the Taco Bell/StarLink incident may change this over time. Coverage in the second hoopla period in Britain reached 75 articles per month in the *Times of London* and 40 per month in the *Daily Mail*.

Who gets quoted in these articles? This is important because their voices help frame the discussion. Results in Table 1 show that both government and university scientists are quoted in only16.7% of stories, and their use has been declining significantly over time in the two British newspapers. Activist groups, on the other hand, have been increasingly used as sources, and now appear in more than 40% of all stories, more than twice as often as scientists. Public officials, including politicians, regulatory agency personnel, and agricultural agencies, are the most frequently used category of sources, appearing in well over half of all stories. Their use has been relatively constant over time. Industry sources (both industry and industry associations) were used heavily by the *New York Times* in the pre-hoopla period, appearing in almost two-thirds of articles, but their use has declined steadily over time to the present 34% of stories.

Table 1 ■ Percentage use of sources by the *Daily Mail*, *New York Times*, and *Times of London*.

Source type	*Daily Mail*	*New York Times*	*Times of London*	Overall
Scientists				
Pre-hoopla	28.6	21.4	33.3	29
First hoopla	22.0	31.8	19.1	24
Post-hoopla	6.1	25.9	10.4	12
Second hoopla	12.0	22.0	16.0	17
	$P = 0.015$			$P = 0.003$
Public officials				
Pre-hoopla	81.6	46.4	46.7	59.1
First hoopla	78.0	52.3	51.1	61.0
Post-hoopla	61.2	66.7	37.5	53.2
Second hoopla	70.0	54.0	66.0	63.3
			$P = 0.04$	
Industry/assoc.				
Pre-hoopla	24.5	64.3	31.7	35.8
First hoopla	16.0	56.8	36.2	35.5
Post-hoopla	26.5	40.7	27.1	29.8
Second hoopla	26.0	34.0	32.0	30.7
		$P = 0.03$		
Citizens groups				
Pre-hoopla	30.6	21.4	30.0	28.5
First hoopla	38.0	45.5	25.5	36.2
Post-hoopla	34.7	37.0	20.8	29.8
Second hoopla	48.0	34.0	42	41.5
Farmers				
Pre-hoopla	6.1	7.1	6.7	6.6
First hoopla	8.0	25.0	10.6	14.2
Post-hoopla	4.1	0.0	4.2	3.2
Second hoopla	20.0	8.0	12.0	13.6
	$P = 0.032$	$P = 0.006$		$P = 0.004$

Chi-square statistical tests were conducted for individual newspapers as well as overall. Only statistically significant results are shown.

sized human health concerns, regulatory issues, and business (Table 2). The *Daily Mail* also focused on moral themes. The *New York Times* focused predominately on business themes until the monarch butterfly hoopla, and then it focused on both business and environmental issues. *New York Times* articles, in part because they tended to be longer, also covered human health and regulatory concerns. When the second hoopla period arrived in May 2000, the British media placed more emphasis on the environment (concern about the spread of GM rapeseed in Britain), along with continued concern about human health. The *New York Times*, on the other hand, emphasized human health and environmental issues, with declining coverage of business aspects.

Tone of coverage, as measured by the presence of positive and negative statements, has been predominately negative in the *Daily Mail*. In the second hoopla, there have been 2.5 negative themes for every positive one. For the entire period studied, almost half of the *Daily Mail* articles contained only negative information. The *Times of London* has 1.5 negative themes for every positive one, with one-third of its articles containing only negative themes. The *New York Times*, in contrast, has been equally likely to present a positive theme as a negative one. One-fourth of its coverage contained only negative themes, whereas 14% were only positive, 36% were both positive and negative, and the remaining one-fourth contained neither positive nor negative themes (Table 3).

Industry sources were not quoted as much in Britain and have remained relatively steady across time at between 26 and 32% of all articles. Although these results concern the **frequency** of use of sources rather than any measure of **importance**, they strongly suggest that scientists are no longer a prominent part of the public dialogue. GM foods have become a **social** issue.

Another indicator that GM foods have become a social issue is that essentially the same scientific issue has been covered differently in Britain and the United States. In Britain, the 1999 hoopla empha-

Conclusions

Coverage of GM crops and other agricultural issues (food irradiation, bovine somatotropin [BST], etc.) in these three newspapers is very uneven over time. It rises steeply when triggering events create a hoopla that focuses public and media attention on a particular issue. These triggering events can be caused by scientific reports in journals or at meetings, but they also may be brought about by nonscientific events (the discovery of GM rapeseed in Britain) or by efforts of individuals (Prince Charles,

Table 2 ■ Percentage of coverage of GMO-related themes in articles across four time periods by *Daily Mail*, *New York Times*, and *Times of London*, 1997–2000.

Part 1

Theme	*Daily Mail*	*New York Times*	*Times of London*	Overall
Human health themes				
Pre-hoopla	42.9	39.3	26.7%	35.0
First hoopla	22.0	29.5	12.8%	21.3
Post-hoopla	12.2	25.9	16.7%	16.9
Second hoopla	32.0	44.0	30.0%	35.4
	P = 0.005			*P* = 0.002
Environmental themes				
Pre-hoopla	16.3	25.0	18.3	19.0
First hoopla	2.0	40.9	12.8	17.7
Post-hoopla	12.2	29.6	18.8	18.5
Second hoopla	54.0	36.0	34.0	42.2
	P = 0.009			
Business theme				
Pre-hoopla	12.2	71.4	25.0	36.5
First hoopla	18.0	54.5	40.4	40.4
Post-hoopla	16.3	29.6	27.1	26.6
Second hoopla	14.0	30.0	6.0	7.5
		P = 0.001		
Morality theme				
Pre-hoopla	38.8	14.3	13.3	22.6
First hoopla	32.0	15.9	12.8	20.6
Post-hoopla	22.4	11.1	16.7	17.7
Second hoopla	34.0	22.0	28.0	28.6
Regulatory Theme				
Pre-hoopla	40.8	32.1	33.3	35.8
First hoopla	42.0	34.1	25.5	34.0
Post-hoopla	20.4	48.1	20.8	26.6
Second hoopla	26.0	28.0	32.0	27.9
	P = 0.05			

Chi-square statistical tests were conducted for individual newspapers as well as overall. Only statistically significant results are shown.

an ardent opponent of GM crops) or organizations (Greenpeace, Environmental Defense Fund, etc.). Many efforts to generate triggering events do not succeed; those that succeed in Britain (Frankenfood) may be different from those that succeed in the United States (monarch butterfly). The interest generated by these triggering events in some cases is sufficient to break through Neuman's (1990) threshold and become something the public is "most concerned about," but most issues do not remain in the mass media for long periods. If not recharged by other news, these issues tend to decline in importance over time. However, it seems likely that in the case of GM foods, developments associated with the release of new GM varieties, public response, and regulatory aspects may keep providing fresh impetus for media coverage.

Coverage of GM food issues demonstrates that 1) volume of coverage has been much greater in Britain than the United States; 2) tone of coverage over time has been more negative in Britain; 3) thematic interest is not always focused on one aspect, but shifts over time in response to triggering events (from human health to environment in Britain; from business to environment in the United States); and 4) the role of scientists and industry in the public debate over GM foods has been declining, whereas the role of activist groups has been increasing.

When a topic becomes a social issue, rather than a scientific issue, many changes occur. Activist groups build fund-raising and awareness campaigns around it. Industry groups and coalitions form and work to shape the debate. Scientists receive increased grant monies to study the problem. Citizens learn about these issues, form attitudes, and occasionally change behaviors. Long term, the outcome is somewhat uncertain. On the one hand, there are examples of social issues such as milk pasteurization—a practice that was controversial and considered "unnatural" when first promoted. The public came to

Table 3 ■ Percentage of articles containing positive, negative, positive and negative, or no positive or negative themes.

Tone of Coverage	*Daily Mail*	*New York Times*	*Times of London*	Overall
Positive only	4.5	14.1	9.8	9.1
Positive and negative	17.2	35.6	21.5	23.7
Negative only	48.0	24.2	34.6	36.6
Neither positive nor negative	30.3	26.2	34.1	30.6

accept this practice, and it is no longer a social issue (it has returned to being a scientific issue). On the other hand, there are examples of social issues such as nuclear power. At the present time, social concerns about this technology, and regulatory responses to production and storage of nuclear material, ended the construction of new nuclear power plants in the United States, and it is still very much a social issue almost 50 years later.

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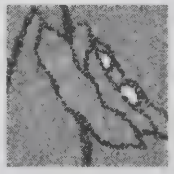
New Developments from Industry

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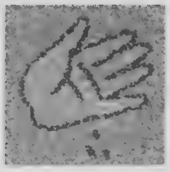

Monarchs and Bt: Sorting Out the Facts

Kevin Steffey

The first spate of controversy regarding the potential effect of *Bacillus thuringiensis* (Bt) corn on nontarget organisms occurred in 1999 after Losey et al. (1999) published a note in *Nature* regarding the toxicity of Bt corn pollen to monarch butterfly caterpillars. The Losey et al. (1999) study generated a media frenzy that fostered a "call to arms" for opponents of transgenic crops. Although media attention on the Bt corn–monarch butterfly issue subsided by early 2000, the issue remained a point of contention. The importance of the issue also generated a significant number of research projects to determine if Bt corn pollen would affect populations of monarch butterflies. The Losey et al. (1999) study had been conducted in the laboratory. Many scientists argued that the potential threat of Bt corn pollen to monarch caterpillars could be assessed only through rigorous field studies. Although field studies had been initiated, no one had published results from any of these studies in 1999.

Controversy arose once again during the summer of 2000 after CBS aired the news feature "Eye on America" by Wyatt Andrews on August 21. The segment focused on an article published electronically for the journal *Oecologia* by Laura C. Hansen Jesse and John J. Obrycki, Iowa State University, Ames. The title of the article was "Field deposition of Bt transgenic corn pollen: lethal effects on the monarch butterfly" available on the Web at http://link.springer.de/link/service/journals/00442/contents/00/00502/. After the CBS news segment aired, media all over the world responded with reports that "fanned the flames" of concern about the potential effects of Bt corn pollen on monarch caterpillars. For several weeks, university and agricultural company scientists, environmental groups, commodity organizations, and biotechnology councils issued points and counterpoints regarding the Hansen Jesse and Obrycki (2000) study.

To form a balanced picture regarding different interpretations of the Hansen Jesse and Obrycki (2000), I offer the abstract of the Hansen Jesse and Obrycki (2000) article and a response by Val Giddings, Vice President for Food and Agriculture of the Biotechnology Industry Organization (BIO). Following is the abstract of the Hansen Jesse and Obrycki (2000) article:

"We present the first evidence that transgenic *Bacillus thuringiensis* (Bt) corn pollen naturally deposited on *Asclepias syriaca*; common milkweed, in a corn field causes significant mortality of *Danaus plexippus* L. (Lepidoptera: Danaidae) larvae. Larvae feeding for 48 h on *A. syriaca* plants naturally dusted with pollen from Bt corn plants suffered significantly higher rates of mortality at 48 h (20±3%) compared to larvae feeding on leaves with no pollen (3±3%), or feeding on leaves with non-Bt pollen (0%). Mortality at 120 h of *D. plexippus* larvae exposed to 135 pollen grains/cm^2 of transgenic pollen for 48 h ranged from 37 to 70%. We found no sub-lethal effects on *D. plexippus* adults reared from larvae that survived a 48-h exposure to three concentrations of Bt pollen. Based on our quantification of the wind dispersal of this pollen beyond the edges of agricultural fields, we predict that the effects of transgenic pollen on *D. plexippus* may be observed at least 10 m from transgenic field borders. However, the highest larval mortality will likely occur on *A. syriaca* plants in corn fields or within 3 m of the edge of a transgenic corn field. We conclude that the

ecological effects of transgenic insecticidal crops need to be evaluated more fully before they are planted over extensive areas."

Following is Val Giddings' statement, issued August 24, 2000:

> Dr. Obrycki's research stands in the shadow of more than 20 independent studies by widely recognized scientific experts who have found that Bacillus thuringiensis (Bt) corn does not pose a significant risk to the monarch butterfly. This report considers only one small area of this complex topic and the conclusions put forward by the authors stand in stark contrast to those of the broader scientific community's research. The Oecologia paper is not truly 'field research' inasmuch as much of what it reports is based on analyses taking place in laboratory manipulations rather than field conditions. Furthermore, the paper clearly shows that larval mortality was not correlated with the number of pollen grains on the plant or the plant location within or at the edge of the field, surprises in search of an explanation. Both the United States Environmental Protection Agency and the Department of Agriculture have studied Bt corn for many years. Just last week the EPA extended the registrations of these products through the 2001 growing season. And in April, the EPA dismissed a Greenpeace lawsuit challenging the Bt plant registrations on a lack of merit, and stated '. . . available scientific data and information indicates that the cultivation of Bt crops has a positive ecological effect, when compared to the most likely alternatives.' To imply that Bt corn has a negative effect on monarch butterflies flies in the face of the fact that last year, more than 28 million acres were planted with Bt corn, an increase of approximately 40% over the previous year. In the same time period, the monarch butterfly population flourished and increased by about 30%, according to Monarch Watch.

So, what's the truth? Hansen Jesse and Obrycki (2000) and Giddings offer rather disparate interpretations of the results of a "field study" to investigate the potential negative effects of Bt corn on monarch caterpillars. Do both interpretations have merit? Facts are facts, but interpretations of scientific findings are subject to . . . interpretation.

Rice (2000) summarized the Losey et al. (1999) study and the preliminary results of the Hansen Jesse and Obrycki study released in 1999. Rice (2000) indicated, "Both studies suggest that some, but not all, monarch caterpillars may be killed when they ear Bt corn pollen. It is not known whether monarch larvae can avoid eating pollen on a milkweed in a natural environment or whether corn pollen is evenly distributed on all leaves on a milkweed. No studies have been conducted to assess the actual mortality of monarchs on milkweed near cornfields."

Rice's (2000) comments are more or less a summary of our knowledge to date, although many ongoing field studies should shed new light on the issue. Sears et al. (2000) placed substantial preliminary results on the Web at http://www.cfia-acia.agr.ca/English/plaveg/pbo/btmone.shtml. Although they have not yet published their research in a scientific journal, their findings have generated significant interest. Sears et al. (2000) found that 90% of the corn pollen fell within 5 meters of the cornfield of study in Canada. They indicated that on average, pollen counts on milkweed leaves were lower than those known to be toxic to neonates and that counts of corn pollen on milkweed plants 5 meters from the field edge were close to zero. Most importantly, they concluded that their "preliminary data did not provide evidence for a strong phonological overlap between monarch larval stages and peak pollen shed in Ontario, 1999." More results from their study and several other field studies were discussed in depth at a workshop held in Chicago, IL, November 16 and 17, 2000.

I read the Hansen Jesse and Obrycki (2000) article carefully, and the study reported was not what I would consider a field study. In fact, even the authors have referred to it as a "modified field study." Although the corn and milkweed plants initially were grown outside in relatively small plots, the mortality information generated was from first-instar monarch caterpillars feeding on milkweed leaf disks (with different amounts of Bt and non-Bt corn pollen) in the laboratory. Another critical point is that although pollen deposition was measured from two types of Bt corn (from event 176 and event Bt11), mortality of monarch caterpillars exposed to field-deposited pollen was measured only for event 176 Bt corn. Less Bt toxin is expressed in event Bt11 pollen than in event 176 pollen. In addition, most of the Bt corn grown in the United States is from event MON810, an event that's virtually the same as event Bt11. The comparative amounts of Bt toxin in events 176 and MON810 are 7.1µg and 0.9 µg Bt toxin/g fresh weight of pollen, respectively. Furthermore, the contrived density of 135 pollen grains/cm^2 was considerably higher than the mean densities of

pollen grains measured on milkweed plants 0.2, 1, 3, 5, and 10 meters from the edge of the Bt corn.

I was dismayed by some of the sweeping conclusions Hansen Jesse and Obrycki (2000) made in reference to the potential effects of Bt corn pollen on monarch caterpillars in the real world. I will not argue that potential limitations of Bt corn and other transgenic crops need to be studied. However, misrepresentation of scientific findings is inappropriate. If scientific evidence reveals negative impacts of transgenic crops, then let the chips fall where they may. But we should be very careful about interpretations of scientific studies.

Furthermore, not all reports of the potential effects of Bt corn on nontarget organisms are negative. Wraight et al. (2000) published a study regarding the potential effects of Bt corn pollen on early instar eastern black swallowtails, *Papilio polyxenes*. The objective of the study was to determine whether mortality of early instar eastern black swallowtails was associated either with proximity to a field of Bt corn or by levels of Bt corn pollen deposition on host plants. They published their results on the Web in the *Proceedings of the National Academy of Sciences USA* on June 6, 2000. The title of the article was "Absence of toxicity of *Bacillus thuringiensis* pollen to black swallowtails under field conditions" and can be viewed at http://www.pnas.org/cgi/content/full/130202097v1.

Black swallowtail caterpillars occur throughout North America east of the Rocky Mountains. They feed almost entirely on plants in the celery or parsnip family, several of which are found in pastures, along roadsides, and edges of cultivated fields. Consequently, these caterpillars may be found feeding on their host plants near Bt cornfields. Wraight et al. (2000) used arrays of potted wild parsnip plants (5 rows of 5 potted plants per row) as hosts for the caterpillars (10 first instars per plant). The potted plants and caterpillars were placed next to a Bt cornfield (Pioneer 34R07; event MON810, Cry1Ab gene) 24 hours after the initiation of pollen shed. The amount of pollen falling on each plant was estimated with microscope slides covered with a thin coat of Vaseline. The number of live larvae on each plant was recorded daily for 7 days; the condition of surviving larvae was determined by weighing each larva at the end of 7 days. In addition, Wraight et al. (2000) conducted bioassays in the laboratory to determine the range of toxicity of pollen from Bt corn (both Pioneer 34R07 and Novartis Max 454 [event 176, Cry1Ab gene]) and non-Bt corn (Pioneer 3489).

Wraight et al. (2000) summarized their results:

> . . . there was no relationship between mortality and proximity to the field or pollen deposition on host plants. Moreover, pollen from these same plants failed to cause mortality in the laboratory at the highest pollen dose tested (10,000 grains/cm^2), a level that far exceeded the highest pollen density observed in the field (200 grains/cm^2). We conclude that *Bt* pollen of the variety tested is unlikely to affect wild populations of black swallowtails. Thus, our results suggest that at least some potential nontarget effects of the use of transgenic plants may be manageable.

Wraight et al. (2000) also stated:

> Larvae of the black swallowtail, by virtue of their multivoltine life history and broader host range in the Midwest, are as, if not more, likely to encounter corn pollen between late June and mid-August during its 8- to 10-day period of anthesis than are larvae of the monarch butterfly, yet under actual field conditions no mortality directly or indirectly attributable to ingestion of endotoxin-containing corn pollen could be detected in our study. This is not to say that monarch butterflies are unaffected by *Bt* corn pollen; however, field studies as well as appropriately controlled laboratory studies are necessary before such a conclusion can be drawn.

The National Research Council (2000) released a report that addresses many of the issues regarding transgenic crops, including the potential effects of transgenic Bt crops on nontarget organisms. They reviewed all studies available to them at the time the report was prepared, so their summaries were balanced. Following is their general conclusion about the potential impact of transgenic crops on nontarget organisms: "Both conventional and transgenic pest-protected crops could have effects on nontarget species, but these potential impacts on nontarget organisms are generally expected to be smaller than the impacts of broad-spectrum synthetic insecticides, and therefore, the use of pest-protected plants could lead to greater biodiversity in agroecosystems where they replace the use of those insecticides." However, they also offered this caveat for registering transgenic crops for commercialization: "Criteria for evaluating the merit of commercializing a new transgenic pest-protected plant should include the anticipated impacts on nontarget organisms compared with those currently used

[both chemical and non-chemical methods which are currently used] pest control techniques."

Potential effects of Bt corn on nontarget organisms continue to generate a great deal of interest. As I mentioned previously, considerable field research regarding the effects of Bt corn pollen on monarch caterpillars was initiated in 1999, and more was conducted in 2000. Results from a lot of these studies will help us determine whether Bt corn pollen will affect *populations* of nontarget insects such as monarch butterflies in the field. These "real-world" studies should help us address the most important questions.

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Transgenic Insecticidal Cultivars for Corn Rootworms: Meeting the Challenges of Resistance Management

Michael E. Gray

The 2001 growing season may be the dawn of a new corn rootworm management era. On June 21, 2000, Monsanto Company submitted a corn rootworm insect resistance management (IRM) proposal to the Environmental Protection Agency (EPA) as a component of their data package for registration approval and exemption from tolerance. Claims of confidentiality regarding the IRM proposal were waived because the information fell within the guidelines outlined by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) 10(d)(1)(A)(B) or (C). The IRM plan specifically requested the "registration of *Bacillus thuringiensis* Cry3Bb protein and the genetic material (Vector ZMIR 13L) necessary for its production in corn." Monsanto intends to use the MaxGard™ for all hybrids that express the Cry3Bb protein with the approved transformation. If the EPA grants approval for commercialization, a very limited launch is anticipated for the 2001 season, primarily in the western Corn Belt. The first transgenic corn rootworm hybrids are likely to be "stacked" and also provide European corn borer, *Ostrinia nubilalis* (Hübner), control. Other companies such as Pioneer Hi-Bred International Incorporated, in cooperation with Mycogen Seeds and Dow AgroSciences, are also in a determined pursuit of a transgenic insecticidal cultivar for corn rootworms. The corporate investment and economic risk associated with this exciting and promising technology are impressive and the pressure to establish a "beachhead" in the lucrative corn rootworm marketplace is intense.

Transgenic insecticidal cultivars offer great potential to serve as the most exciting and effective tool for corn rootworm control in the pest management arsenal. It is for this very reason that their utility be as prolonged as possible. This end requires their judicious use within a well-designed resistance management plan. The temptation to overuse transgenic hybrids for corn rootworm control is anticipated and should be resisted. In this article, I offer some of my reactions to Monsanto's IRM plan that was submitted to the EPA during summer 2000.

Resistance Management Considerations for Transgenic Rootworm Hybrids

At the 1999 Crop Protection Technology Conference (Gray 1999), I outlined many of the biological and ecological aspects of corn rootworm biology that should be considered in the development of resistance management plans for this important complex (western and northern corn rootworms [*Diabrotica virgifera* LeConte and *Diabrotica barberi* Smith & Lawrence, respectively]). I stated that the potential for resistance development by corn rootworms is much more acute than for European corn borers. Reasons for this opinion include knowledge of dispersal characteristics of larvae (Suttle et al. 1967; Short and Luedtke 1970; Strnad et al. 1986; Strnad and Bergman 1987a,b; Gustin and Schumacher 1989; MacDonald and Ellis 1990; Strnad and Dunn 1990) and adults (Ruppel 1975, Witkowski et al. 1975, Coats et al. 1986, Grant and Seevers 1989, Youngman and Day 1993), narrow host range (Branson and Ortman 1967a–c, Branson and Ortman 1970, Branson 1971), injurious nature of two life stages within a single growing season, and a

history of resistance development to several insecticides (Ball 1983, Metcalf 1986, Gray and Luckmann 1994, Meinke et al. 1998).

At the 2000 Crop Protection Technology Conference (Gray 2000), I described the potential role of transgenic insecticidal cultivars for corn rootworms within an integrated pest management (IPM) framework. Published research to date differs sharply on the value of scouting and use of thresholds to determine accurately the need for a soil insecticide. Foster et al. (1986) concluded the following: "The optimal strategy for managing corn rootworms in Iowa in our study was not to sample for adults and always to treat corn following corn with a soil insecticide at planting time." In contrast, Stamm et al. (1985) reported that scouting and the use of a threshold (1 adult per plant in August) was reliable >80% of the time in helping producers decide whether a soil insecticide was needed at planting. If the economic threshold was reduced (0.75 adult per plant in August) the predictive accuracy increased to 90%. In the Nebraska research project (Stamm et al. 1985) soil insecticide use declined from 90 to 28%. Can the use of corn rootworm transgenic insecticidal cultivars be used within the framework of an IPM program that is based upon scouting and the use of economic thresholds? Although this strategy cannot be used for the management of European corn borers with transgenic hybrids, for corn rootworms the possibility exists. Arguments for and against the selective use of transgenic corn rootworm hybrids based upon scouting and the use of thresholds can be traced back to Stamm et al. (1985) or Foster et al. (1986), respectively.

Monsanto's IRM Plan for Corn Rootworms

Monsanto's IRM plan "is designed to maintain product durability for at least 15 years." Monsanto also suggests "that an effective insect resistance management plan must meet two fundamental needs: 1) it must be scientifically rigorous and meet certain technical criteria to truly reduce the risk of resistance development; and 2) it must contain elements to achieve grower understanding, implementation, and compliance. A single plan for both corn rootworm and lepidopteran control can meet these criteria. This plan involves having an IRM strategy that transparently overlays the plan presently used for lepidopteran-control products." The paradox with Monsanto's premise is their plea for the implementation of a robust and scientifically based IRM plan for their corn rootworm transgenic hybrids while lobbying for an IRM plan that resembles that of the European corn borer. Key elements of Monsanto's IRM plan for MaxGard™ hybrids include the following (Davis et al. 2000):

- "Growers will be required to plant a minimum of 20% of their corn acres to non-CRW (corn rootworm) control corn."
- "Growers will have the option of applying conventional insecticide treatments (including seed treatments, granular or foliar applications) to the non-CRW control corn refuge."
- "Growers will be encouraged to plant their non-CRW control corn acreage adjacent to or within their CRW control corn acreage where feasible, and will be required to plant the refuge within one-half mile of their CRW control corn acreage."
- "The refuge may be placed on continuous corn acres, but the refuge may only be placed on first-year corn acres if the transgenic corn also has been placed on first-year corn acres."
- "The refuge may be planted in the form of continuous blocks near or adjacent, perimeter strips around, or blocks/strips within the CRW control cornfields."
- "Mixtures of CRW control and non-CRW control seed are not being recommended at this time until further data are gathered on the suitability of this arrangement."
- "Growers should not depend upon a single tactic or technology. For example, crop rotation will remain a key cultural strategy for managing rootworm populations in many regions."
- "Customers (growers and seed distributors) will be instructed to contact Monsanto or an authorized distributor if incidents of unexpected levels of target insect damage occur during use of the CRW control corn products."
- "Upon identification of a confirmed instance of resistance, we will take the following immediate mitigation measures: 1) Notify customers and extension agents in the affected area. 2) Recommend to customers and extension agents in the affected area the use of alternative control measures to reduce or control the local target pest population."

A 20% Refuge Requirement

After much debate, industry, USDA–ARS, and land-grant scientists finally reached consensus that a 20% refuge should satisfy a portion of the requirements of an effective IRM plan when transgenic cultivars are used for European corn borer control. This plan rested on many complex assumptions concerning the biology and ecology of European corn borers, the potential initial frequency of resistant alleles, and the possible expression characteristics (dominant, recessive, or additive) of resistant alleles. The IRM plan with respect to European corn borer transgenic hybrids also has a two-pronged thrust, the so-called "high dose/refuge strategy." In essence, an exceedingly high percentage (>99.99%) of European corn borer larvae are supposed to die when they feed upon transgenic hybrids that express Cry1Ab, Cry1Ac, or Cry9c proteins. Such high levels of mortality are not anticipated for corn rootworm larvae that feed on MaxGard™ hybrids. Davis et al. (2000) reported that Monsanto's corn rootworm transgenic hybrids that are intended for commercialization express the Cry3Bb protein only at low- (20% of homozygous susceptible, SS, larvae may survive) to-moderate levels. This suggests that some corn rootworm larvae will survive after feeding upon corn roots and emerge as adults. Is a 20% refuge the optimum level from an IRM perspective when a transgenic hybrid will provide only low-to-moderate Cry protein expression levels? If corn rootworm survival is sufficiently high on a transgenic cultivar, is a refuge needed at all? How much consideration should mixtures of transgenic and nontransgenic seed be given within an IRM program? Davis et al. (2000) suggests that "More research is needed with seed mixtures to better understand their potential value as a refuge strategy." The use of transgenic and nontransgenic seed mixtures is not recommended within an IRM program for European corn borer because of the high-dose events that are commercialized. However, for low-to-moderate dose corn rootworm transgenic cultivars, if given the option, producers would certainly like the simplicity of planting seed mixtures.

Although the temptation is to keep an IRM plan for corn rootworm transgenic hybrids as similar as possible to the IRM plan for European corn borers, significant differences in Cry protein expression levels between European corn borer and corn rootworm transgenic hybrids, casts considerable doubt that a "one size fits all" refuge is based on solid ground. However, the refuge component of the Monsanto's IRM plan does offer convenience and simplicity and some may argue that because we can only speculate on the ideal size and deployment pattern for a refuge, why not forge ahead with the 20% plan? Producers may be more apt to follow an IRM plan that is similar for both of these key insect pests of corn. If refuge plans become too cumbersome and distinctly different for corn rootworms and European corn borers, producers may choose to ignore them.

Insecticide Use within an IRM Plan

Another component of Monsanto's IRM plan for corn rootworm transgenic cultivars concerns their recommendation that growers be allowed to use insecticides to prevent losses from corn rootworms in a refuge. The potential use of granular soil insecticides, seed treatments, and foliar applications would be allowed under their recommended IRM guidelines. Because soil insecticides are not population suppression tools (Gray et al. 1992), their use in a refuge would allow for plentiful adult emergence while at the same time provide root protection. The proponents who call for the banning of granular soil insecticides should be well advised that this "accomplishment" would ultimately work against the implementation of a more fully integrated management program for corn rootworms. By providing producers with a broader array of pest management tools, including granular soil insecticides and transgenic cultivars, we prolong the potential usefulness of both tactics. Although seed treatments such as ProShield™ and Prescribe™ are marketed aggressively to producers for corn rootworm control, they have proven ineffective in their ability to prevent larval injury under moderate-to-heavy corn rootworm pressure. For the control of secondary insect pests, insecticidal treatments could offer some benefits in conjunction with the use of corn rootworm transgenic cultivars. However, improvements in seed treatment technology are needed before producers can rely comfortably upon them for control of corn rootworms as "stand alone" products in a refuge. Because corn rootworm adults may prune silks and interfere with the pollination process, producers may be inclined to apply a foliar application of an insecticide to limit this damage. A foliar application to a refuge will serve to reduce significantly the number of corn rootworm adults

and is the least desirable use of an insecticide from an IRM vantage.

Refuge Placement

Monsanto's IRM plan encourages producers to plant their refuge "adjacent to or within their CRW control corn acreage where feasible." Farmers will be required "to plant the refuge within one-half mile of their CRW control corn acreage." Monsanto's IRM plan for corn rootworm transgenic cultivars also provides these specifics: "The refuge may be planted in the form of continuous blocks near or adjacent, perimeter strips around, or blocks/strips with the CRW control cornfields." In recognition of the growing problem of western corn rootworm injury to rotated corn (O'Neal et al. 1999) in the eastern Corn Belt, Davis et al. (2000) placed the following restriction on refuge placement: "The refuge may be placed on continuous corn acres, but the refuge may only be placed on first-year corn acres if the transgenic corn also has been placed on first-year corn acres." With the exception of the refuge placement requirement on first-year corn acres, the corn rootworm IRM refuge guidelines closely parallel those used for European corn borers despite the significant differences in the mating behavior of both species.

Upon emergence from corn residue, European corn borer adults (males and females) fly to nearby grassy areas found within ditch banks, roadsides, or waterways. Within these "action sites" females emit a pheromone that attracts males and mating ensues (Showers et al. 1980). During the evening, shortly after sunset, females leave action sites and travel to nearby cornfields to lay eggs. Early planted fields are most attractive to the first flight of females. In contrast, the second flight of egg-laying females is most attracted to late-planted fields that are actively shedding pollen. Unlike females, male moths are more prone to remain in action sites and flight is generally more limited. The refuge placement component of the IRM plan for European corn borer rests upon some of these fundamentals: 1) males and females typically leave blocks of corn (transgenic corn [larval survival should be exceedingly rare] and nontransgenic corn); 2) males and females congregate in action sites outside of cornfields, or in grassy waterways within fields; 3) mating generally occurs outside of cornfields; 4) mating of adults from separate fields can occur within the same action site; 5) male movement is more limited than that of females; 6) after mating, females return to cornfields to lay eggs; and 7) egg-laying females are unable to distinguish between transgenic and nontransgenic hybrids.

Unlike European corn borer adults, mating of corn rootworm adults occurs within fields, most frequently in those fields from which they have emerged. Male corn rootworms typically emerge first and females that emerge subsequently are mated without much delay (Branson et al. 1977). The critical point is that movement (from field to field) by corn rootworm adults prior to mating is limited. Sustained long-distance flights are possible for western corn rootworm females; however, they are most apt to occur in mated and preovipositional females (Coats et al. 1986). With such significant differences in the mating behavior and dispersal characteristics of European corn borers and corn rootworms, why are the IRM plans with respect to refuge placement so similar? Should convenience and simplicity dictate the course we chart?

Because of mating and dispersal characteristics of corn rootworms, the placement of numerous refuge strips within a field may offer greater IRM advantages compared with block or separate field refuges. Ensuring the greatest mixing of corn rootworm alleles may not be enhanced with blocks or separate field refuges. Although Monsanto's first registered transgenic cultivars for corn rootworms will express at low-to-moderate dose levels, the future use of high-dose events may necessitate the deployment of in-field refuges as part of an overall sound IRM program. However, the results of modeling efforts to date differ somewhat in their assessment of the IRM advantages of refuges planted in strips versus the use of refuges planted in separate blocks or adjacent fields. For instance, Onstad et al. (2001) argue that refuges deployed as strips will result in a shorter time for the evolution of resistance (3% resistant allele frequency) to transgenic cultivars compared with separate blocks. With refuges deployed as strips within growers' fields, the time for resistance development (3% resistant allele frequency) was 13 and 34 years with refuges of 5 and 30%, respectively. Onstad et al. (2001) suggested: "Selection pressure may be greater with row strips because of the greater likelihood of oviposition in the transgenic strips compared to separate blocks." Continued debate and further modeling efforts will seek to address the IRM advantages and disadvantages of separate blocks or fields versus the use of in-field refuges.

In spite of the continuing concerns over exports of transgenic grain to foreign markets, American farmers eagerly anticipate the registration and commercialization of corn rootworm transgenic cultivars. The acres planted to transgenic corn rootworm hybrids are expected to far exceed those devoted to European corn borer transgenic hybrids. The purchase of a transgenic hybrid for European corn borers represented an added management cost for most producers because this pest was often largely ignored until harvest (Pilcher and Rice 1998). Producer interest in corn borer transgenic hybrids has waned in recent years because of jittery overseas markets and low densities of this insect pest. Demand for corn rootworm transgenic hybrids will be fueled by many factors: 1) producer knowledge that they are simply substituting one already commonly accepted input cost (soil insecticides) for that of another, 2) keeping the cost of transgenic seed and soil insecticides comparable, 3) whether crop rotation management problems associated with corn rootworms intensifies, 4) whether resistance to some foliar insecticides in the western Corn Belt spreads, and 5) whether foreign concerns subside regarding the export of transgenic grain.

Davis et al. (2000) are to be commended for making the following statement: "Growers should not depend upon a single tactic or technology. For example, crop rotation will remain a key cultural strategy for managing rootworm populations in many regions." Unfortunately, the track record for the judicious use of pest management tools for corn rootworms has not been a glowing success story. The heavy prophylactic use of soil insecticides on continuous corn, the continued development of insecticide resistance in Nebraska to broadcast treatments of insecticides (Meinke et al. 1998), and the collapse of crop rotation as a corn rootworm management tool in the eastern Corn Belt (O'Neal et al. 1999) all point to the over-reliance upon a single tactic by producers. Expectations are that producers will most likely repeat history when it comes to their use of transgenic cultivars for corn rootworms.

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Hybridization among the Amaranths: Implications for Herbicide Resistance Evolution

Patrick J. Tranel and James J. Wassom

The development of herbicide-resistant weed populations continues to pose significant weed management challenges to crop producers throughout the world. From atrazine to glyphosate, nearly every herbicide has selected for resistant weed biotypes. The development of resistant weed populations occurs because of the basic principles of natural selection. Herbicides exert selection pressure by controlling susceptible plants. Meanwhile, plants with genes conferring herbicide resistance are able to survive and reproduce, causing an increase in frequency of the resistance genes. Over a few years of repeated application of a particular herbicide, a herbicide-resistance gene, which initially may have occurred at a *one-in-a-billion* frequency, may become present in nearly every plant of the population.

For a herbicide-resistant population to develop, however, a resistance gene must exist within that population. In other words, selection of resistance genes cannot occur if such genes do not exist. So, from where do these resistance genes come?

Typically, the source of herbicide-resistance genes is simply the natural genetic variation of the species. Because of naturally occurring mutations, which result in more or less random genetic differences, no two plants within a given species are identical. If the population is large enough, by chance there will be at least one plant in the population that has a genetic mutation that confers resistance to a particular herbicide. To prevent such a mutation from increasing in frequency, i.e., to prevent resistance development, one must use different selection pressures. This is why practices such as using multiple herbicide modes of action each season, rotating herbicides, and including tillage are recommended strategies for delaying resistance development.

A second potential source of resistance genes in a given weed population is through introduction from another population. That is, resistance may develop in one population and subsequent seed movement can initiate resistance development in another population. Preventative weed management procedures, such as cleaning implements between fields and planting weed-free seed, can block this route of resistance development. Although seed movement is one obvious way whereby resistance genes may move from one population to another, pollen movement also may accomplish the same thing. Whether by seed or pollen movement, introduction of resistance genes from other populations can rapidly increase the areas infested with herbicide-resistant populations.

Recently, a third potential source of resistance genes has received increased attention. The commercialization of herbicide-resistant crops has raised the concern that "superweeds" could be created by movement of resistance genes from crop to weed. For this to occur, however, the resistant crop and weed must be able to hybridize. Fortunately, this is not of great concern for corn or soybean in the Midwest because of the lack of coexisting, related weed species. In some regions, however, crops do coexist with closely related weed species (e.g., wheat with jointed goatgrass, canola with various mustards, cultivated sunflower with weedy sunflowers) and movement of herbicide-resistance genes from the crop into these weeds is a legitimate concern.

In addition to movement of resistance genes from crop to weed species, it is also possible that resistance genes may move from one weed species to another. Many weeds exist as complexes of closely related species. The foxtails and pigweeds are two such examples. It is known that hybridization may occur between species within these complexes. So, might this be an important route for evolution of herbicide resistance?

Hybridization among Weedy Amaranthus Species (Pigweeds)

It has been known for years that at least some of the weedy *Amaranthus* species can cross to produce hybrid progeny (Murray 1940). More recently, our research and that of others has specifically addressed whether herbicide resistance could evolve in an *Amaranthus* species as a result of hybridization with another *Amaranthus* species.

Wetzel et al. (1999) determined that herbicide-resistance genes could be transferred from waterhemp to Palmer amaranth. Both of these *Amaranthus* species are dioecious (separate male and female plants), and therefore are dependent on outcrossing for seed production. This fact, combined with the apparent genetic relatedness between the two species, sets up an ideal opportunity for cross-species hybridization to occur. Using a dominant gene conferring resistance to acetolactate synthase (ALS)-inhibiting herbicides as a marker and controlled crosses in a growth chamber, Wetzel et al. (1999) obtained several hybrids between the two species. All of these hybrid plants appeared to be fertile and, furthermore, at least one of these hybrids was able to backcross with the herbicide-sensitive parent (Palmer amaranth) and produce viable offspring. As expected, a proportion of these backcross progeny carried the dominant herbicide-resistance gene. Thus, these studies confirmed that waterhemp could serve as a donor of herbicide-resistance genes, thereby providing a route for herbicide-resistance evolution in Palmer amaranth.

We have been investigating whether waterhemp can hybridize with smooth pigweed, redroot pigweed, and Powell amaranth. Hybridization of waterhemp with these three species is expected to be less likely to occur than hybridization between waterhemp and Palmer amaranth because smooth pigweed, redroot pigweed, and Powell amaranth 1) are monoecious species (male and female flowers on the same plant) and therefore are less likely to outcross, and 2) apparently are less closely related genetically to waterhemp than is Palmer amaranth. Nevertheless, waterhemp and these three species (smooth pigweed in particular) often coexist in Illinois corn and soybean fields. Consequently, if herbicide resistance can move between waterhemp and these three species, it would have important implications to Illinois crop producers.

We attempted a total of four crosses: common waterhemp as the male parent crossed to each of the monoecious species, and smooth pigweed as the male parent crossed to common waterhemp. For each cross, the male parent contained a dominant gene for resistance to ALS-inhibiting herbicides. Crosses were conducted by daily bringing the desired male and female plants into proximity and shaking the male plants to encourage pollen shed. At all other times during flowering, female parents were isolated by species in separate greenhouses or growth chambers. When a monoecious species was the desired female parent, the likelihood for hybridization was further increased by daily removing its anthers (pollen-producing structures).

From each cross, numerous plants were obtained that survived treatment of an ALS-inhibiting herbicide. Most of these survivors were confirmed to be hybrids by molecular analysis, which indicated the plants contained a copy of the ALS gene from each of the parent species. Although morphological features were variable among hybrids, many exhibited features characteristic of both parent species. Of several dozen hybrid plants analyzed, all but one were dioecious, and among these there were similar numbers of male and female plants. All of the male plants apparently were sterile. The female plants had greatly reduced fertility; some seeds were produced, however, upon backcrossing to one of the parent species. Twenty backcross plants were confirmed to be of hybrid origin by molecular analysis. Of these backcross plants, derived from a common waterhemp by smooth pigweed hybrid backcrossed to common waterhemp, all were dioecious and only two were males. The male plants had low fertility but the female plants appeared to be fully fertile and produced numerous seeds. Thus, our findings to date indicate that introgression of herbicide resistance between at least some dioecious and monoecious *Amaranthus* species can occur.

Implications

What is the significance of hybridization between waterhemp and other *Amaranthus* species such as smooth and redroot pigweed? The significance arises because waterhemp has been very successful at evolving resistance to various herbicides. Many fields in Illinois, probably more than half, contain waterhemp resistant to ALS-inhibiting herbicides (Patzoldt and Tranel, unpublished data). Several waterhemp populations exhibit resistance to triazine herbicides, and, in fact, there exists a waterhemp biotype in Illinois resistant to both ALS-inhibiting and triazine herbicides (Foes et al. 1998). Furthermore, there is at least some evidence for resistance to glyphosate in waterhemp (Zelaya and Owen 2000). Although herbicide resistance also has evolved in other pigweeds, it appears to evolve more rapidly in waterhemp. For example, resistance to ALS inhibitors is so prevalent among Illinois waterhemp populations that these herbicides are not recommended for waterhemp control. In contrast, ALS-inhibiting herbicides are generally effective on Illinois populations of smooth and redroot pigweed.

By crossing with herbicide-resistant waterhemp plants, other pigweed species may evolve resistance more rapidly than would occur if they relied on their own genetic variability. One can envision a model whereby waterhemp, being very genetically diverse and promiscuous, rapidly evolves resistance to various herbicides. By its subsequent hybridization with other, less diverse *Amaranthus* species, these species also might develop resistance.

Our crossing experiments were conducted in a specific attempt to obtain hybrids, and therefore the potential for hybrid formation was optimized. The frequency at which fertile hybrids between *Amaranthus* species is produced in the field is unknown; a recent report, however, indicates it does happen (Pratt and Owen 2000). Also, one must remember that hybridization is only one part of the equation. The mechanism of herbicide resistance and the number of genes involved could greatly influence whether resistance to a particular herbicide is transmitted across species boundaries. Nevertheless, results from the recent studies described herein reveal the potential importance of an oft-overlooked mechanism for evolution of herbicide resistance. As the pest management community has learned, mechanisms and examples of pest evolution that were once thought to be only "theoretically possible" often become reality.

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Resistance Management Concerns in Weed Science

Micheal D. K. Owen

During the past decade, there has been considerable discussion about herbicide resistance and the impact of herbicide-resistant weed populations on crop production. Although herbicide-resistant weeds in corn, specifically weeds resistant to triazine herbicides, have been relatively common since the late 1970s, the introduction of herbicides that inhibit acetolactate synthase (ALS) in the early 1980s escalated the evolution of herbicide-resistant weed populations in the Midwest. Despite considerable effort by university scientists and the agricultural chemical industry to educate growers on effective management techniques to minimize the evolution of herbicide-resistant weed populations, the rate at which they develop continues to increase (Heap 2000a).

Generally, row crop production in the Midwest is more flexible and has more tools and alternative strategies to manage weeds than many other crop production systems. However, considerations other than actual production practices are more pervasive and have resulted in growers focusing on herbicides as the most important, if not sole means of managing weeds. This strategy tends to support the evolution of herbicide-resistant weed populations. Thus, the questions that must be answered are whether herbicide-resistant weed populations represent a significant problem to growers, either currently or in the future, and will proactive management of herbicide-resistant weed populations increase profitability for corn and soybean producers.

Weeds, Agriculture, and Herbicides

Although growers often assume that there is considerable uniformity in crop production systems over broad geographic regions, each field potentially has unique genetic and ecological characteristics that affect the development of the associated pest complex (Gould 1991). These characteristics result in differences from field to field regarding the effectiveness of pest management tactics. Weed populations that develop in a particular field are adapted to that particular agroecosystem. The adaptation of weeds, and thus the economic importance of the associated weed populations, can be generally described as mimicry (Baker 1991). Essentially the weed population is able to mimic the crop and thus exist in the field. Mimicry can be described as vegetative (Baker 1974), seed (Barrett 1983), and of current importance, biochemical (Holt and LeBaron 1990). Vegetative and seed mimicry do not play an important role in Midwest agriculture, however biochemical mimicry (herbicide resistance) is prevalent.

The prediction of herbicide resistance occurred prior to the widespread use of herbicides (Harper 1956). As agriculture became less diverse with regard to crop rotations and tillage, and as the efficiency of production increased, growers adopted simpler weed management systems until herbicides became the most important weed management tool. The lack of weed management diversity and reliance on herbicides has increased the importance of herbicide-resistant weeds in the Midwest (Dieleman and

Mortensen 1998). Currently, there are 233 herbicide-resistant weed biotypes in the world, encompassed by 150 different weed species (Heap 2000a). Countries with highly developed and intense agriculture account for more than 90% of the herbicide-resistant weed populations.

Historically, when a "new" weed problem developed, a "new" herbicide became available that controlled the weed, thus providing growers with an easy and effective tool (Norton and Conway 1977). As a result, weed management can be more appropriately described as herbicide management, and the biological principles that affect the interactions between crops and weeds have been ignored. The resulting evolution of herbicide-resistant weeds is evidence that weed scientists and agronomists have not effectively managed an important pest complex.

Importantly, the rate of herbicide resistance evolution has been more rapid than what biological wisdom might predict (Gould 1991). Unfortunately, the development of new herbicides to "manage" the new resistant weeds has slowed. Furthermore, with the widespread use of herbicide-resistant crops and the appropriate herbicide, management practices have further simplified, thereby increasing the selection pressure on weed populations. This simplification may result in greater problems with herbicide resistance at a time when agricultural producers need the most effective and efficient weed management to reduce resource consumption and achieve economic and environmental sustainability (McPhee 1994).

Current and Future Herbicide-Resistant Weed Issues

Eighty herbicide-resistant biotypes have been reported in the United States (Heap 2000b). The most widespread and (likely) economically important herbicide resistance is to the ALS inhibitor herbicides. Resistance to ALS herbicides is widely dispersed throughout the Midwest in corn, soybean, and small grain systems. For example, common sunflower (*Helianthus annuus*) (Baumgartner et al. 1999) and waterhemp (*Amaranthus* spp.) (Hinz and Owen 1997) populations that are resistant to several ALS inhibitor herbicides have been reported. Newer ALS resistance problems include giant foxtail (*Setaria faberi*) (Volenberg et al. 2000), shattercane (*Sorghum bicolor*) (Anderson 1997), giant ragweed (*Ambrosia trifida*) (Mark Loux, personal communication), kochia (*Kochia scroparia*) (Foes et al. 1999), and woolly cupgrass (*Eriochloa villosa*). It is critically important that the ALS-resistant weed populations evolved within 5 years of the initial use of the ALS inhibitor herbicides (Shaner 1996). However, with the change in herbicide use, it is questionable whether the rapid evolution of ALS resistance will continue.

The other current issue for herbicide-resistant weed evolution reflects the increase in Roundup Ready soybean and concomitant use of glyphosate as the sole tactic for weed control. Although weed management has been excellent and growers generally see this system as the most effective and efficient strategy for weed control, problems appear to be developing. Monsanto has reported that goosegrass (*Eleusine indica*) populations have evolved resistance to glyphosate (Dill et al. 2000). Rigid ryegrass (*Lolium rigidum*) populations also demonstrated resistance to glyphosate (Powles et al. 1998). Across the Midwest, common waterhemp (*Amaranthus rudis*) control has been variable with glyphosate. Investigations of these common waterhemp populations suggest that resistance can develop (Zelaya and Owen 2000). Whether resistance to glyphosate will become a major problem remains to be seen, although it is very likely that weed control problems with glyphosate will increase in the future. Research to elucidate the specific mechanism(s) by which common waterhemp demonstrates a differential response is currently underway.

Regardless of the specific crop system or herbicide, strategies to control herbicide-resistant weeds in corn and soybean were identified by agricultural chemical dealers as a top research priority (Stoller et al. 1993). Scientists suggest that herbicide-resistant weed populations are inevitable (Hueth and Regev 1974) and current systems that use single tactics to control every weed are doomed to fail (Mortensen et al. 2000). It is imperative to diversify tactics to manage herbicide resistance (Boerboom 1999). Growers might be better served if they focused on the general ecological principles affected by crop production strategies (Parker 1976). However, the ecological, environmental, and economic risks of alternative tactics to manage herbicide-resistant weed populations must be compared with current technologies. If the diverse alternative strategies do not demonstrate profitability in the near future, growers will not switch despite the risk of herbicide-resistant weeds (Gressel et al. 1996).

Summary and Conclusions

Generally, the private and public sectors have not successfully curtailed the development of herbicide resistance (Owen 1996). Compared with alternative tactics, herbicides have provided for several decades of consistent weed control (Matthews 1994). Contrary to evidence suggesting that alternative management techniques will effectively deter the development of herbicide-resistant weed populations, herbicides will likely continue to be the primary tactic for weed management in corn and soybean (Menalled and Gross 2000). There is no pervasive evidence that proactive management prior to the development of herbicide-resistant weeds will increase profitability.

Furthermore, there is little evidence to suggest that herbicide-resistant weeds represent a significant threat to the production of corn and soybean (Heap and Peeper 1998). The appearance of herbicide-resistant weeds in corn and soybean production systems is typically limited to isolated individual fields and only those specific growers are likely to experience increases in production costs. Genetically modified organism (GMO)-based weed management systems are viewed to be the answer to herbicide-resistant weeds and thus have been widely adopted in the Midwest. These systems are extremely effective and generally consistent regarding weed control. However, there is little functional difference between the GMO-based systems and traditional herbicide-based systems. Essentially, growers have changed one herbicide for another and thus the use of GMO-based systems represents only a short-term solution to herbicide resistance. Future problems of herbicide resistance are likely to continue despite the use of GMO-based systems. However, as with traditional herbicide-based systems, herbicide resistance in GMO-based systems is not likely to be a widespread significant economic problem.

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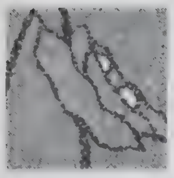

New Strategies for an Old Pest: Rethinking Bean Leaf Beetle Management

Marlin E. Rice, Rayda K. Krell, Wai-Ki F. Lam, and Larry P. Pedigo

The bean leaf beetle is an annual pest of soybean in midwestern states. Adult beetles feed on any aboveground plant part and are especially fond of soybean pods late in the growing season. Larvae, which are similar in appearance to corn rootworm larvae, feed below the soil surface on soybean nodules, but their impact on yield or plant health is not known. In addition to the physical injury that bean leaf beetle adults cause to soybean plants, this insect also transmits bean pod mottle virus—a potentially yield-robbing plant disease that makes proper management of this insect even more critical. This report focuses on a new concept for managing second-generation bean leaf beetle adults, the performance of insecticides in controlling this pest, and the problems related to bean pod mottle virus and transmission by adult beetles.

Table 1 ■ Seasonal occurrence of bean leaf beetles in central Iowa.[1]

Cycle	Begin	Peak	End
Overwintered population	Mid-May	Late May	Late June
First generation	Late June	Mid-to-late July	Mid-to-late August
Second generation	Early August	Late August/mid-September	Late September

[1]From Smelser and Pedigo (1991).

There are two generations of bean leaf beetle in Iowa (Table 1). Bean leaf beetle adults are commonly found on alfalfa after emerging from overwintering habitat. These overwintered populations, which are actually adults from the second generation of the previous growing season, move quickly into soybean, sometimes as soon as the plants crack the ground. This colonization of soybean is typical in Iowa, but because the overwintering bean leaf beetle population is usually small, adults often are not obvious on young soybean plants. The first generation typically occurs on late-vegetative- and early-reproductive-stage soybean. The second generation occurs mostly on soybean in all stages of pod development. It is common for adults from the end of the first generation and the beginning of the second generation to occur at the same time in a field, thereby making the two populations indistinguishable from each other.

A 12-year population study conducted by Larry Pedigo, Iowa State University, shows that the bean leaf beetle population has steadily increased during the past 4 years (Fig. 1). It is believed that the

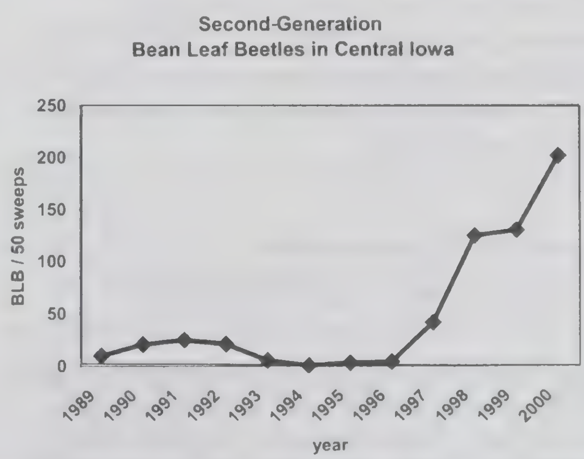

Figure 1 ■ A 12-year population trend for second-generation bean leaf beetles in central Iowa soybean.

relatively mild winters of the past 3 years have allowed above-average survival of overwintering beetles. This situation, coupled with an increase in the acres of early-planted (April) soybean, has contributed to damaging populations of bean leaf beetles throughout most of Iowa. Bean leaf beetle management requires that each of the three population cycles be scouted and considered separately.

Table 2 ■ Early-season (stage V1) bean leaf beetle economic thresholds in soybean.[1]

Crop value ($/bushel)	Treatment cost per acre (insecticide + application)						
	$7	$8	$9	$10	$11	$12	$13
	Beetles per plant						
$5.00	4.4	5.0	5.6	6.2	6.8	7.4	8.0
	Beetles per foot of row						
$5.00	33.4	38.0	42.6	47.1	51.7	56.2	60.8

[1] From Hunt et al. (1995) with economic thresholds calculated at 0.75 of economic injury levels

Economic Thresholds—Overwintered Beetle Population

Overwintered bean leaf beetles feed on new plant tissue and can quickly cause noticeable injury to seedlings in the form of defoliation and scarring of the stem, hypocotyl, and cotyledons. But noticeable injury does not necessarily translate into economically significant damage. Early-season damage does not gain economic significance until cotyledons are lost and regrowth is suppressed by feeding activity. Economic damage requires huge densities of feeding adults, and treatments are rarely justified. Table 2 shows the number of beetles per plant (or foot of row) needed to justify insecticide treatment. Three or more adults per plant are rare but may be possible in localized areas.

Economic Threshold—First-Generation Beetles

Soybean plants have a tremendous capacity to tolerate 30-40% defoliation during the vegetative stages of plant growth. Therefore, adult densities must be extremely large before an insecticide application is economically justified. Fields in Iowa are rarely treated for first-generation beetles because field sampling seldom detects economically damaging populations.

Economic Threshold—Second-Generation Beetles

Bean leaf beetles feeding on soybean pods can lead to significant reductions in seed quality and yield throughout Iowa. Management of bean leaf beetles on soybean during the pod setting and filling stages can be frustrating for farmers and crop advisers because adult beetles may feed on pods for several weeks before the density reaches the economic threshold. In this situation, some loss in seed quality and quantity occurs before an insecticide application is economically justified. The challenge is to try to prevent economic damage before it occurs.

During the past 15 years, entomologists at Iowa State University have been researching the biology and behavior of bean leaf beetles on soybean. We now have sufficient research-based information to make a management decision for second-generation bean leaf beetles based on the population size of the first generation. This concept is radically different from most other approaches to using economic thresholds in field crops.

A degree-day model was developed to estimate the occurrence of first-generation adults in the field (Zeiss et al. 1996) that we converted from Celsius to Fahrenheit. Degree-day estimates for the first generation of adults were 1212 degree days with a developmental threshold at 46°F. Overwintered female beetles usually begin to lay eggs after colonizing soybean fields. The degree-day estimation for first-generation adults is calculated by accumulating the temperature starting at the week of soybean emergence. Table 3 shows the accumulated degree days in 2000 for the first-generation adults from May 1 through June 28 in five different areas of Iowa. Table 4 shows the dates predicted for the peak emergence of first-generation adults at these locations.

The new management concept is to sample the first-generation of beetles and use this information to manage the second generation of beetles in a field. Here's how it works:

Table 3 ■ Degree-day accumulations for first-generation bean leaf beetle adults (1212 degree days with developmental threshold of 46°F) from the date of soybean emergence through June 28, 2000.

Date of soybean emergence	Degree-day accumulations: Decorah (Northeast)	Burlington (Southeast)	Des Moines (Central)	Omaha (Southwest)	Spencer (Northwest)
May 1–7	1039	1221	1240	1308	1158
May 8–14	884	1075	1088	1158	1002
May 15–21	788	960	980	1044	911
May 22–28	708	850	859	918	823

Table 4 ■ Predicted dates for peak emergence of first-generation bean leaf beetle adults.

Date of soybean emergence	Degree-day accumulations: Decorah (Northeast)	Burlington (Southeast)	Des Moines (Central)	Omaha (Southwest)	Spencer (Northwest)
May 1–7	July 7	June 28	June 27	June 24	July 1
May 8–14	July 15	July 5	July 4	July 1	July 7
May 15–21	July 20	July 10	July 9	July 6	July 11
May 22–28	July 24	July 15	July 14	July 11	July 15

1. Determine what week soybean plants emerged from the soil.
2. Consult Table 4 (left-hand column) and find the dates that match the soybean emergence date.
3. Determine which of the five Iowa locations is closest to your field.
4. Where the date (row) and location (column) intersect represents the predicted date for peak first-generation beetle emergence.
5. Sample the soybean fields 1 week after the predicted peak emergence. If the number of beetles reaches or exceeds the threshold (Table 5), stop sampling. If the sample is below the threshold, sample again the following week. If the sample remains below the threshold, sample a third and final week. If the threshold is not reached, then an economic infestation of bean leaf beetles should not occur in your pod-stage soybean.
6. If the first-generation population is above the threshold, scout the fields again in mid-August to monitor for the first emerging beetles of the second generation. If beetles are present, spray the field with an insecticide (45-day preharvest interval or less). Based upon the density of the first generation, it is expected that the second generation will exceed the economic injury level (break even point).

Fields can be sampled for first-generation beetles by using either a drop cloth or a sweep net. Procedures for sampling are as follows.

Drop Cloth

- Walk 100 feet in from the field edge and scout each field and each variety separately.
- Place a 3-foot-wide strip of cloth on the ground between the rows.
- Bend the plants of one row over the cloth and shake them vigorously.
- Count the number of beetles on the cloth.
- Repeat the procedure four times for each 20 acres of the field.
- Determine the average number of beetles per 3 feet of row.

- Consult Table 6 for the number of beetles per 3 feet of row necessary to justify insecticide treatment for the second-generation adults in August.
- If the number of beetles is below the economic threshold, sample the fields again the following week, or a third week if necessary.

Table 5 ■ First-generation bean leaf beetle populations necessary to predict economically damaging second-generation bean leaf beetles.[1]

Crop value ($/bushel)	Treatment cost per acre (insecticide + application)								
	$7	$8	$9	$10	$11	$12	$13	$14	$15
	Beetles per 3 feet of row								
$5.00	5.6	6.4	7.2	7.9	8.7	9.5	10.3	11.0	11.8
	Beetles per 20 sweeps								
$5.00	23.0	26.2	29.4	32.6	35.8	39.0	42.2	45.4	48.6

[1] Economic thresholds are based on a row spacing of 30 inches and a plant population of eight plants per foot of row. For narrow-row soybeans (8-inch rows) and a plant population of three plants per foot of row, multiply the above-mentioned economic thresholds by 0.7.

Sweep Net

- Walk 100 feet in from the field edge and scout each field and each variety separately.
- Sample the beetles for 20 sweeps by sweeping **down** the row, not across the row.
- Repeat the procedure four times for each 20 acres of the field.
- Determine the average number of beetles per 20 sweeps.

Table 5 shows the number of first-generation beetles per 20 sweeps that justifies insecticide treatment for the second-generation beetles.

If the number of beetles is below the economic threshold, sample the fields again on following week, or a third week if necessary.

Management with Insecticides

A variety of insecticides are labeled for management of bean leaf beetles. Insect control is always a prime consideration when selecting a product to use, but another consideration in choosing an insecticide is the length of the preharvest interval. Commonly available insecticides and their preharvest intervals are Ambush 2EC (60 days); Asana XL (21 days); Lorsban 4E (28 days); Penncap-M (20 days); Pounce 3.2EC (60 days); Sevin XLR Plus (Rhone-Poulenc label states "5 days," whereas the Aventis label states "within 21 days of harvest of dried beans or peas, seed, or hay"); and Warrior T (45 days). A 60-day preharvest interval may exclude some chemicals from being used, especially for late-season insect management.

There is little published information on the performance of insecticides labeled for control of bean leaf beetles on soybean. An exception is the work of Ron Hammond (1996), an entomologist at The Ohio State University. Hammond evaluated Sevin (carbaryl) and the new pyrethroid Warrior (lambda-cyhalothrin) during 1994 and 1995, to test the long-term efficacy against second-generation bean leaf beetles. Hammond stated "pyrethroids are excellent insecticides because of their low active ingredient rates, excellent efficacy against a wide range of insects, and long residual activity. The efficacy of pyrethroids is often extended beyond that of other insecticides because of their ability to repel insects."

Hammond found that even though bean leaf beetle populations were low during the experiments, there was a significant difference in the performance of the Sevin and Warrior treatments (Tables 6 and 7). In 1994, Warrior kept the beetles out of the plots for up to 4 weeks. Similar results were found in 1995 with both rates of Warrior providing better control than the Sevin treatment.

Hammond suggested that it was unlikely that sufficient residues of Warrior capable of causing mortality persisted on the plants for the 4 weeks of the experiment, but that repellency was most likely the cause of lower insect densities near the end of the experiment.

In summer 2000, Ken Pecinovsky, Nashua Research Farm, Iowa State University, expanded on the work of Hammond. Soybean was planted on May 10 in 30-inch rows. On August 10, a large population of bean leaf beetles was found in R5 (beginning seed)-stage soybean; the beetle population averaged 132.8 beetles per 20 sweeps. Five treatments were established in the field: 1) Warrior T (3.2 oz/acre),

Table 6 ■ Post-treatment counts of second-generation bean leaf beetles in soybean treated with insecticides, Ohio, 1994.[1]

		Bean leaf beetles/20 sweeps (mean ± S.E.)[2,3]			
Treatment	Rate/acre	Week 1	Week 2	Week 3	Week 4
Warrior T	2.96 oz.	0.7 ± 0.7	0.3 ± 0.3b	0.0 ± 0.0c	1.3 ± 0.7b
Sevin XLR	0.75 pint	2.0 ± 1.2	10.7 ± 3.8a	13.0 ± 2.1b	27.0 ± 8.3a
Check	—	1.3 ± 0.7	10.0 ± 0.6a	21.0 ± 3.5a	27.0 ± 4.5a

[1] From Hammond (1996).
[2] Week 1, 2, 3, and 4 are August 23, 30, September 6, and 13, respectively.
[3] Numbers in the same column and followed by the same letter are not significantly different ($P > 0.05$, LSD).

Table 7 ■ Post-treatment counts of second-generation bean leaf beetles in soybean treated with insecticides, Ohio, 1995.[1]

		Bean leaf beetles/20 sweeps (mean ± S.E.)[2,3]			
Treatment	Rate/acre	Week 1	Week 2	Week 3	Week 4
Warrior T	1.92 oz.	0.0 ± 0.0	0.3 ± 0.3c	1.3 ± 0.3b	1.8 ± 0.8c
Warrior T	2.96 oz.	0.0 ± 0.0	0.5 ± 0.3c	0.5 ± 0.3b	1.3 ± 0.6c
Sevin XLR	0.75 pint	0.0 ± 0.0	3.4 ± 1.9b	10.5 ± 3.4a	10.8 ± 3.6b
Check	—	0.8 ± 0.5	7.5 ± 0.9a	17.5 ± 6.3a	23.2 ± 5.5a

[1] From Hammond (1996).
[2] Week 1, 2, 3, and 4 are August 23, 30, September 6, and 14, respectively.
[3] Numbers in the same column and followed by the same letter are not significantly different ($P > 0.05$, LSD).

2) Lorsban 4E (2 pints/acre), 3) Sevin XLR (2 pints/acre), 4) Furadan 4F (0.5 pint/acre), and 5) an untreated check. All insecticide treatments were applied in 20 gallons of water per acre broadcast over the row. Plots were eight rows in width and 60 feet in length. Treatments were applied on August 10 and each was replicated four times in a randomized complete block design. Twenty sweeps were taken in each plot on August 16, 24, 31, and September 7 (approximately 1, 2, 3, and 4 weeks, respectively) after application. Beetles were counted at the end of each 20-sweep sample and released back into the plot from which they were collected. Soybean was machine harvested on September 30.

One week after application, the bean leaf beetle density was reduced significantly in all insecticide treatments with Warrior and Lorsban providing the best level of control (Table 8). Two weeks after application, bean leaf beetle densities increased in all plots but were substantially smaller in the Warrior and Lorsban treatments compared with

Table 8 ■ Insect densities and soybean yields from insecticide plots treated for second-generation bean leaf beetles, Iowa, 2000.

		Bean leaf beetles/20 sweeps (mean ± S.E.)[1,2]				Bushels
Treatment	Rate/acre	Week 1	Week 2	Week 3	Week 4	per acre
Warrior T	3.2 oz.	0.5 ± 0.3c	24.5 ± 4.8d	40.5 ± 5.5b	3.3 ± 0.3b	61.8 ± 0.7a
Lorsban 4E	2 pints	5.3 ± 2.0c	45.3 ± 2.7d	22.8 ± 3.6c	11.5 ± 1.3b	58.3 ± 0.7b
Sevin XLR	2 pints	9.3 ± 2.5bc	127.3 ± 6.6c	63.5 ± 5.4a	40.0 ± 3.9a	59.4 ± 1.2b
Furadan 4F	0.5 pint	30.5 ± 3.6b	168.8 ± 13.1b	59.8 ± 10.1a	40.8 ± 10.0a	59.1 ± 0.8b
Check	—	94.8 ± 14.3a	206.3 ± 14.7a	61.3 ± 3.2a	44.5 ± 6.8a	58.8 ± 0.9b

[1] Week 1, 2, 3, and 4 are August 16, 24, 30, and September 7, respectively.
[2] Numbers in the same column and followed by the same letter are not significantly different ($P > 0.05$, LSD).

Sevin and Furadan. Three and 4 weeks after the initial insecticide application, there was a natural decline in the insect population, but the Warrior and Lorsban treatments continued to suppress the beetle population to levels significantly lower than the other insecticides. The 4-week control of Warrior was similar to the findings of Hammond. The performance of Lorsban in our study was nearly identical to that of Warrior. In spite of the performance of the insecticides in reducing insect densities, a significant yield benefit was detected only in the Warrior treatment.

Bean Leaf Beetle and Virus Transmission

In 1999 many soybean producers from Iowa reported problems with soybean green stem, and mottled or discolored soybean seed. Many of these reports of poor soybean quality were suspected as caused by the spread of a soybean disease, bean pod mottle virus. This virus has been a problem in the southern United States since the 1950s. Bean pod mottle virus was identified in Iowa as early as 1968 (Quiniones and Dunleavy 1971) but it hadn't been widespread or implicated in causing significant yield losses. Bean pod mottle virus was confirmed in soybean during 1999 in several central and western Iowa counties (Dallas, Ida, Marshall, Polk, Story, and Woodbury). Unconfirmed reports suggest that it may be present in all but the northern two tiers of Iowa counties.

Bean pod mottle virus is a disease that can infect soybean and other legume species. Potential problems with bean pod mottle virus are twofold: reductions in soybean quality and yield. Symptoms of bean pod mottle virus can resemble injury from herbicide drift, or symptoms of soybean mosaic virus. Symptoms also may vary depending on the soybean variety and growing conditions. Infected soybean plants may have mottled or crinkled leaves and plants may be stunted. At maturity, infected plants are associated with mottled soybean seeds. The effect of bean pod mottle virus on soybean yield also may be variable, but losses of more than 50% were noted in some studies (Hopkins and Mueller 1984). Bean pod mottle virus also can occur in combination with soybean mosaic virus, resulting in even greater yield reductions. Seed transmission of bean pod mottle virus has been documented, but so far the percentage reported was less than 0.1%.

The main pathway for bean pod mottle virus entry into soybean plants is through insect feeding. The main known vector for this virus is the bean leaf beetle. When beetles feed on soybean leaves they produce a small amount of regurgitated plant material. If this regurgitant comes from a previous plant that was infected with virus, it can infect a healthy plant on which the beetle is feeding. Other vectors for this virus have been reported, including blister beetles and southern corn rootworm beetles; however, the bean leaf beetle is considered the most important vector in Iowa because of its abundance and statewide distribution.

There is some controversy over whether the virus overwinters in bean leaf beetle adults. One study found that the virus could overwinter in adult beetles that would create a mode for early infection of soybean. Beetles could obtain the virus from infected soybean plants in the fall and infect soybean as soon as they emerge from overwintering sites and enter soybean fields the next spring. However, other work has shown that bean pod mottle virus does not stay infective in adult beetles throughout the winter (S.A. Ghabrial, personal communication). It also is possible that adult beetles may obtain the virus by feeding on infected wild legumes in the early spring and then transmit the virus to soybean at plant emergence. Although we don't know exactly when beetles may be transmitting bean pod mottle virus, we do know that the earlier soybean is infected, the greater the potential reduction in yield (Hopkins and Mueller 1984).

The only way to determine whether a plant is infected with bean pod mottle virus is to test for virus presence. Soybean plants that have the above-mentioned symptoms would be good candidates for testing; however, disease symptoms are identical to soybean mosaic virus. Diseased plants should be sent to a reputable plant disease laboratory for confirmation.

If soybean is infected, the best way to manage the virus is to manage bean leaf beetle populations. If bean leaf beetle adults were abundant in your fields last year, you will likely have them again in 2001. Very cold winter temperatures reduce the population, but not necessarily below economically damaging levels. If bean pod mottle virus symptoms were observed in your fields, you may want to consider an early-season insecticide treatment when the adults first invade the field. This management strategy is being tested in Iowa for its ability to prevent viral infection of the crop and reductions in

grain quality and quantity. The reason this strategy may be difficult to implement is that timing an insecticide application for early-season beetles is difficult because beetles leave overwintering sites and colonize soybean fields over one or two weeks. Because there is so much that we are still learning about the virus–beetle–soybean relationship, we cannot state confidently that an early insecticide treatment is the best management tactic. We will be evaluating this management strategy again in 2001.

Another option for managing early-season beetles is to plant soybean later in the season to deter colonization of fields by bean leaf beetles adults. Even delaying planting until mid-to-late May can reduce bean leaf beetle densities in a field and possibly reduce incidence of the disease in the crop.

There is still a tremendous amount to learn about bean pod mottle virus and its relationship with bean leaf beetles. A cooperative project between plant pathologists and entomologists at Iowa State University has begun exploring many of the basic questions about the disease and potential management strategies. The economic thresholds that we currently use do not consider the potential disease transmission role of adults and the impact of bean pod mottle virus, a glaring limitation in our understanding of these interacting and complex pest problems.

Additional information on bean leaf beetle management, including photographs of the insect and plant injury, can be found at www.ipm.iastate.edu/ipm/icm/ Check this site for updates on bean leaf beetles during the growing season.

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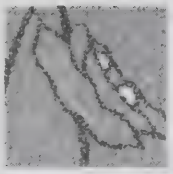


Fall Behind or Spring Ahead: Where Are Fall-Applied Herbicides Going?

Christy L. Sprague and Aaron G. Hager

Recently, the concept of fall applications of certain soil-applied soybean herbicides has generated some interest and raised several questions about this weed management practice. What are advantages and disadvantages of fall herbicide applications? Are there benefits to this practice? Are there any serious limitations? Is fall a good time of the year to be thinking about weed management?

First, not every soil-applied soybean herbicide is labeled for fall application. And although the idea of fall-applied soybean herbicides is new to most people, some herbicide formulations (for example, trifluralin) have been labeled for fall applications for many years. The "new" thrust for fall-applied soybean herbicides originates in the idea that if a herbicide is applied to no-till ground in the fall, it may help to reduce or eliminate the growth of winter or early summer annual weed species. Winter annual weed species such as purple deadnettle, henbit, chickweed, horseweed (marestail to most folks), and a number of mustard species can add both color and headaches to no-till soybean fields during the spring. The prevalence of these winter annual weed species has increased during the past few years, probably due to extremely mild winters and the increased use of certain postemergence herbicides that lack significant soil residual activity. Mild winters have extended the growing season, allowing for more growth of these winter annual species. Dense populations of winter annual weeds can physically interfere with soybean planting and may reduce soil drying, resulting in a delay in soybean planting. So, if a herbicide with soil residual activity is applied in the fall before most winter annual weed species germinate, it may help reduce the amount of vegetation prior to soybean planting, perhaps eliminating the need for a burndown herbicide application. Although the idea may sound good in theory, the actual results may or may not be as good as expected. Several factors determine ultimately how well this system works.

Location in the state

Anyone who has traveled the length of Illinois during early spring observes a "gradient" with respect to when "green-up" occurs. Growth of winter or early summer annual weed species in no-till fields begins much earlier in the southern portions of the state. Typically, weed growth is much further along in southern counties when burndown herbicide applications are made to fields. So it's not too surprising that much of the interest in fall-applied soybean herbicides occurs below a line south of Springfield. It's not unusual for producers in this region to apply a burndown herbicide to weeds that are a few inches to more than 1 foot in height. Soils often take longer to dry after precipitation in the southern third of Illinois than the "darker" soils of central and northern Illinois, further delaying the application of burndown herbicides. Even though fields may be too wet to till or plant, the weeds continue to grow.

Herbicide selection and application rate

Currently, there are several soybean herbicides labeled for fall application to the soil. In addition,

several corn herbicides are labeled for fall application. Some of the current soybean herbicides labeled for fall applications to the soil include Canopy, Canopy XL, Sencor, Sencor + Python, Steel, and Backdraft. For each of these products, many questions linger regarding their use during the fall: 1) Which herbicide provides optimum control of certain winter annual species? 2) When is the best time to apply a given product during the fall? 3) For some products, are spray additives needed? 4) Which application rates are the most appropriate for the different products? 5) Do certain winter annual weed species present more significant control challenges than others? 6) Are tank mixes of other herbicides (2,4-D, glyphosate) required to provide the necessary level of control? and 7) If tank mixes of herbicides are required, what product rates are needed?

Concerns to ponder

One of the major concerns regarding the fall-application of residual herbicides is the length of time after a treatment until soybean are planted, on average a span of at least 6 months. Rainfall and snowmelt may have a major impact on how much of the herbicide remains by the time soybean are planted. Precipitation and herbicide degradation due to soil microorganisms increase the likelihood that herbicide activity may be diminished by spring. This concern may be lessened if fall applications are intended primarily to reduce the density of winter annual weeds at planting; however, it may not be lessened if producers are looking for guaranteed control of summer annual weed species. Fall-applied residual soybean herbicides also limit the choice of crop that can be planted in the spring because several of these herbicides have crop rotational restrictions.

Have we conducted any research on fall-applied soybean herbicides?

Yes, we have 1 year of data. We initiated an experiment during fall 1999 at four locations (DeKalb, Urbana, Brownstown, and Altamont) to examine the efficacy of fall-applied soybean herbicides. The locations offer a good north-to-south gradient and also provide the needed diversity in weed species. At each location fall herbicides were applied in mid-November. The herbicides included Canopy, Canopy XL, and Sencor (two rates), with and without Roundup Ultra + 2,4-D. Roundup Ultra + 2,4-D (1.5 pt + 0.5 pt) also was applied alone to evaluate the effectiveness of this treatment without a residual herbicide. As expected, the results of these treatments were variable.

Table 1 ■ Winter annual weed control from fall applications of several herbicides with and without Roundup Ultra (RU) + 2,4-D (1.5 pt + 0.5 pt) at soybean planting.

		Common chickweed[1]		Purple deadnettle[2]		Mustard species[3]	
Herbicide[4]	Rate (oz)	Alone	w/RU + 2,4-D	Alone	w/RU + 2,4-D	Alone	w/RU + 2,4-D
		% control					
Canopy	3.0	71	99	99	99	99	99
Canopy	7.0	97	99	99	99	99	99
Canopy XL	2.5	50	99	96	99	99	99
Canopy XL	6.8	72	99	99	99	99	99
Sencor	4.0	6	80	99	99	88	92
Sencor	10.0	54	91	99	99	98	98
Untreated		0	83	0	37	0	83
$LSD_{(0.05)}$		— 17 —		— 7 —		— 10 —	

[1] Common chickweed present at Brownstown and Urbana.
[2] Purple deadnettle present at Brownstown.
[3] Mustard species consisted of shepherd's-purse, field pennycress, etc. These species were present at Altamont and Urbana.
[4] All soil-residual herbicides applied alone contained 1% v/v crop oil concentrate.

As mentioned previously, there can be considerable differences in winter annual weed growth in northern and southern Illinois. For example, in DeKalb (northern location), no weeds were present during the fall application or even at planting, including the untreated plots. This suggests that areas in northern Illinois (north of I-80) are probably not well suited for fall soybean herbicide applications to control winter annual weeds because these weeds are not as much of a problem compared with those in southern Illinois.

However, we had some good results from fall herbicide applications at Urbana, Brownstown, and Altamont. At planting, fall-applied Canopy (7.0 oz/acre) was the most consistent soil-applied herbicide for controlling common chickweed, purple deadnettle, and winter annual mustard species (Table 1). Henbit control was excellent and was not different among any of the herbicide treatments. Many of the winter annual species were present when the fall applications were made, and even fall application of Roundup Ultra + 2,4-D provided greater than 80% control of common chickweed and mustard species at the time of soybean planting. Both rates of fall-applied Canopy and the highest rate of Canopy XL (6.8 oz/acre) also controlled common lambsquarters and common ragweed by spring planting (Table 2). Even though we observed some positive results this year, final conclusions are premature with only a single year of data. We plan to repeat this research during fall 2000.

Table 2 ■ Summer annual weed control from fall applications of several herbicides with and without Roundup Ultra (RU) + 2,4-D (1.5 pt + 0.5 pt) at soybean planting.

		Common lambsquarters[1]		Common ragweed[2]	
Herbicide[3]	Rate (oz)	Alone	w/RU + 2,4-D	Alone	w/RU + 2,4-D
		% control			
Canopy	3.0	99	96	98	82
Canopy	7.0	98	94	97	95
Canopy XL	2.5	91	98	84	90
Canopy XL	6.8	99	99	93	97
Sencor	4.0	7	7	7	7
Sencor	10.0	43	27	24	23
Untreated		0	0	0	0
$LSD_{(0.05)}$		— 15 —		— 15 —	

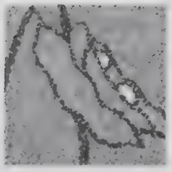
[1] Common lambsquarters present at Urbana.
[2] Common ragweed present at Brownstown and Urbana.
[3] All soil-residual herbicides applied alone contained 1% v/v crop oil concentrate.

Should perennial weed species be treated in the fall?

Perennial weed species often become established in no-till production fields and can sometimes cause a great deal of frustration with respect to how best to control or eradicate them. Without the option of mechanical control (i.e., tillage), perennial weed species are generally best controlled by postemergence translocated herbicides (those that can move into the roots). The selection of a specific translocated herbicide as well as application timing can affect the level of success achieved.

Perennial weed species are frequently difficult to control because they store a large amount of food reserves in their root systems. Controlling the aboveground part of perennial species is usually not enough to achieve satisfactory, long-term control; the root system must be controlled as well. Translocated herbicides are usually the most effective chemical option for the control of perennial weed species, but application timing is important. In the spring, perennial species rely on stored food reserves to initiate new growth, so most reserves are moving upward to support new vegetative development. Thus, it is often difficult to get an adequate amount of herbicide into root tissue when applications (for example, burndowns) are made in the spring. Better control of perennial broadleaf species can be achieved when applications of postemergence translocated herbicides are made when these species have begun to flower. Another good time to treat perennial weed species is during the fall. As day length becomes shorter and temperatures become cooler, perennial plant species begin to move food reserves back into their roots. Because these reserves are moving downward in the fall, more translocated herbicide is shifted into root tissue of these perennial species, and control is generally much greater than can be achieved during the spring.

Dandelions are often very common in no-till production systems and frequently are not controlled by spring burndown applications of translocated herbicides. Greater rates of certain translocated herbicides can frequently be used in the fall compared with the spring. For example, 2,4-D is used commonly as a burndown herbicide in the spring, but usually at only 1 pt/acre. There is an increased potential for soybean injury at rates greater than 1 pt/acre and a longer required interval is necessary prior to planting. Fall applications should be made before many hard frosts have occurred. Leaf tissue damage caused by hard freezes usually decreases herbicide absorption.



What Did We Learn about Soybean Aphids in 2000? Expectations for 2001

John L. Wedberg, Craig R. Grau, Nancy C. Kurtzweil, John M. Gaska, David B. Hogg, and Tom H. Klubertanz

Background

The soybean aphid, *Aphis glycines* Matsumura, a serious pest of soybean in China, was first detected in the United States on July 13, 2000, in a research trial conducted by us on a private farm near Whitewater, WI. Although the aphids we collected appeared to be the cotton/melon aphid, *Aphis gossypii* Glover, an aphid already present in the United States, we forwarded specimens to Dr. David Voegtlin at the Illinois Natural History Survey for additional examination. Dr. Voegtlin determined that the aphids were soybean aphid; the cotton/melon aphid and the soybean aphid closely resemble one another and separation of the two species is difficult. The cotton/melon aphid is reported to colonize soybean in China. And there also are reports that the two species can hybridize when they overwinter on the same plant. By the fall of 2000 the presence of soybean aphid had been confirmed in nine states, but it appears that the heaviest infestations were present in Wisconsin, Michigan, and northern Illinois.

Life History

Most of our information on soybean aphid is based on literature from China and a few other Asian countries (Takashi et al. 1993), where the optimal range of temperature and humidity for the aphid has been reported to be from 71 to 77°F and less than 78%, respectively (Wang et al. 1962). During 2000, the soybean aphid's behavior in Wisconsin was very close to that reported by Wang et al. (1962). In China the winter host is *Rhamnus davurica*, a species of buckthorn. The summer host range is limited to wild and cultivated soybean. Although *R. davurica* is not known to occur in Wisconsin, we have at least five other species of buckthorn and some of these have escaped cultivation as a landscape plant and can be found in woodlots, fencerows, and similar areas. Additionally, winged forms of the soybean aphid have flown from soybean plants to cuttings of buckthorn in laboratory trials conducted at the University of Wisconsin, Department of Entomology. Buckthorn is critical to survival of soybean aphid because females lay eggs on buckthorn in the fall. To survive winter in the upper Midwest, aphids must produce cold-tolerant eggs.

Three periods of damage to soybean have been identified in China:

1. From seedling stage to blooming stage of soybean, the aphid population reaches its peak. Colonies concentrate on tender leaves and branches (i.e., new trifoliolate leaves).
2. In late July, the top growing point of soybean stops growing, and the aphids move from the top of the plant to middle or lower areas of the canopy and feed on the undersides of soybean leaves. At this time of the year, soybean aphids are much smaller and more yellow than forms found earlier in the growing season.
3. From late August to early September, the aphid colonies begin to multiple rapidly again. Thereafter, they disperse to the overwintering host, where eggs are laid.

The winged aphids that move from buckthorn to soybean early in the growing season are females and they give birth to living young, without fertilization, by an asexual process called parthenogenesis. They initially colonize stem apices and young leaves. Winged and wingless females are present during the growing season, and the winged forms leave plants to seek out new soybean plants when populations become crowded, or perhaps in response to a decline in plant quality.

The parthenogenetic females give birth to winged males that fly to buckthorn to mate with females during late summer to early fall. Reproduction is now sexual, rather than asexual, and the females lay eggs on buckthorn. During 2000, we first detected winged sexual aphids in a late-planted soybean field on September 29, which was a few weeks later than the timetable described for China.

Damage

Soybean aphids damage soybean by sucking plant sap and stressing the plant. They also are capable of transmitting plant viruses during feeding. Affected plant parts include the whole plant (leaves, stems, and growing points), whereas affected plant stages include seedling, vegetative, and flowering. Two of the viruses that soybean aphid is known to vector in China, soybean mosaic potyvirus and bean yellow mosaic virus, are already present in the United States. It is not possible to control the spread of these viruses by controlling the aphids with insecticides.

Heavily infested plants are stunted and have distorted leaves. Sooty mold grows on the honeydew excreted by the aphids and results in charcoal-colored residue on stems, leaves, and pods. In Wisconsin during 2000 many of the infested fields we visited also exhibited plants with leaves with a yellow halo around the leaf edge, which is also a symptom of potassium deficiency. Premature leaf drop can result when aphid infestations are heavy, but such leaf losses also are associated with potassium deficiency. Tissue testing and subsequent soil tests in fields expressing these symptoms during 2000 indicated the plants were potassium deficient. Perhaps the stress from aphid feeding exacerbated the effect of potassium deficiency.

Wang et al. (1994) inoculated soybean at the two-leaf stage with 5–220 soybean aphids per plant. The number of aphids per plant and plant infestation rate were closely related to yield losses, which were 2.7–51.8% at 5–220 aphids per plant. Aphid infestation at the seedling stage affected yield mainly by reducing plant height and numbers of pods and seeds.

Wang et al. (1996) also reported that heavily infested plants (more than 70,000 aphids per 100 soybean plants) had fewer pods per plant, lower test weight of seed, and reduced yield. Anecdotal information from China indicates that growers spray from two to five times during seasons with high aphid abundance.

Relationship between planting date and damage

Wisconsin fields that were double-cropped after a previous crop, such as succulent peas produced for processing, had higher aphid numbers and greater expression of injury symptoms than fields planted from late April to mid-May. It is not known whether the late-planted fields (after mid-June) were more attractive to colonizing aphids or whether the nutritional quality of the younger plants provided for a more rapid buildup in aphid densities.

Variety Response

Results from University of Wisconsin and seed company variety trials indicate the aphids demonstrate varietal preferences that are distinct from maturity effects. Table 1 summarizes data for a variety trial conducted near Whitewater, WI, in which we monitored aphid populations and leaf area index. Plots were planted on May 15 and aphid populations were sampled on August 16, 2000, by taking five leaf core samples (3.9 cm in diameter) from the upper part of the plant canopy in each plot. In addition to significant differences in aphid numbers among varieties, the leaf area indices taken during the R2, R4, and R6 stages suggest a differential variety response to aphid feeding.

Role of Biological Control in 2000

Harmonia axyridis (Pallas), the multicolored Asian lady beetle, was the most common predator associated with aphid-infested soybean fields during 2000. Other predators were observed commonly and included green lacewing larvae, damsel bugs,

Table 1 ■ Comparison of soybean cultivars for aphid population density and LAI ratings, Whitewater, WI.

Company	Entry	8/16/00 Aphids per sample[2]	7/14/00 LAI[1] (R2 stage)	8/14/00 LAI[1] (R4 stage)	9/7/00 LAI[1] (R6 stage)
Asgrow	AG 2201	39	1.93	4.45	3.31
Asgrow	AG2401	32	1.90	3.95	3.06
Asgrow	AG2301	37	2.02	4.21	3.59
Asgrow	AG2001	79	1.89	4.65	3.55
Dairyland	DSR218	76	1.99	4.04	2.69
Dairyland RR	DSR241	38	2.07	4.94	3.85
Dairyland	DSR277	20	1.91	4.38	3.39
Golden Harvest	H-2519	32	2.15	4.01	2.97
Hughes	Hughes225	50	1.87	3.87	2.28
Hughes RR	Hughes261	45	1.78	3.50	2.80
LG Seeds	LG6200	60	1.76	4.30	3.21
Mark	Mark9927	20	1.82	4.40	3.40
Midwest	G2380	24	2.16	3.88	3.39
Mycogen	MYC5261	27	1.79	4.31	3.23
Novartis	S24-92	63	2.04	4.52	3.29
Public	Sturdy	49	2.37	4.31	3.06
Public	Corsoy79	139	1.70	3.77	2.81
Public	Hardin	79	1.77	3.19	2.55
Public	BSR101	55	2.39	4.70	3.18
Public	Jack	27	1.61	3.70	3.29
Public	Dwight	27	1.82	4.09	3.52
Spansoy	Spansoy 250	50	2.02	4.47	3.24
Spansoy	Spansoy 201	68	1.89	3.98	2.52
Trelay	Trelay248	35	1.76	4.16	3.05
Probability%					
Entry		<0.01	1.80	0.10	0.14
LSD (0.10)					
Entry		30	0.32	0.59	0.55
CV%					
		42	14	12	15

[1] LAI expressed in m/m^2.

[2] Aphids per 19.5-cm-diameter sample (six leaf core samples per plot and 3.9 cm in diameter).

minute pirate bugs, syrphid maggots, and cecidomyid larvae. However, predators will probably be unable to keep aphid densities below damage thresholds during severe outbreaks. The aphids can produce young too rapidly for predators, alone, to bring populations under control. Additionally, we did not find high levels of parasitism of aphids. An unidentified fungal pathogen(s) was the major biological control factor and was the major component responsible for the crash in aphid populations during August. Aphids that are killed by this fungus are brown to reddish brown and are usually found on the lower surface of the soybean leaf.

Insecticides

Farmers that decided to spray for soybean aphids during 2000 were faced with a situation in which there were no insecticides labeled for aphids in soybean, nor were there insecticide efficacy data available for soybean aphids. Applicators used insecticides labeled for soybean that were labeled for aphids on other crops. Results were mixed, but most insecticide application occurred when the plant canopy was closed and aphids had moved down the plant and located on the lower surface of leaves. Most of the aphids probably escaped insecticide contact.

Table 2 summarizes the results of an insecticide trial at the University of Wisconsin Arlington Agricultural Research Station. Experimental plots were planted on May 16, 2000, in 30-inch rows designed to study the potential role of transient insects as vectors of soybean viruses prior to our discovery of soybean aphids in Wisconsin. Spansoy 201 and 250, with or without protection with Warrior T 1EC, were monitored throughout the season. Warrior was applied at

Table 2 ■ Effect of Warrior 1EC on soybean aphid population density and soybean plant height (University of Wisconsin Arlington Agricultural Research Station).

Variety	Treatment	Aphids per sample[1] 8/03/00	Height (in.) 8/03/00	Height (in.) 8/11/00	Height (in.) 8/24/00
Spansoy201		51.0	31.1	33.4	35.2
Spansoy250		44.0	29.7	37.1	42.4
	None	86.0	28.9	33.5	37.0
	Warrior	9.0	31.6	37.1	40.6
Spansoy201	None	88.0	29.7	31.4	33.3
Spansoy201	Warrior	13.0	32.6	35.4	37.1
Spansoy250	None	84.0	28.1	35.6	40.7
Spansoy250	Warrior	4.0	30.6	38.7	44.1
Mean		47.0	30.3	34.2	38.8
Probability%					
Variety		>50	10.8	3.1	0.38
Treatment		2.20	5.60	8.5	4.80
V X T		>50	48.9	>50	>50
LSD (0.10)					
Variety		NS	NS	2.20	2.10
Treatment		17.3	1.50	3.10	1.70
CV%					
		62	2	5	4

[1] Aphids per 38.4-cm-diameter sample (24 leaf core samples per plot and 1.6 cm in diameter).

0.02 lb AI/acre on June 22 (V2 growth stage), July 5 (V5), July 14 (R2), and August 2 (R4) to suppress insect populations. Aphids were sampled in each plot by taking 24 leaf cores, 1.6 cm in diameter, and counting all aphids on each core.

Although there were no leaf abnormalities from aphid feeding in the unsprayed plots, plants were significantly shorter than those in sprayed plots, and the plant canopy took longer to close. The plant height and canopy differences are reflected in the leaf area index (LAI) ratings taken on each sampling date (Table 1).

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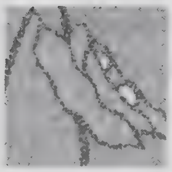

Soybean Viruses in Illinois

Glen Hartman, Houston Hobbs, Les Domier, Wayne Pedersen, Daren Eastburn, Eli Levine, Joe Spencer, and Scott Isard

Introduction

Diseases caused by viruses frequently affect soybean. Worldwide, 47 viruses have been reported to infect soybean plants under field conditions (Tolin 1999). Of these, five have been documented on soybean in Illinois; however, there have not been systematic surveys for viruses in the state. Therefore, the occurrence and distribution of viruses throughout Illinois is not known. Based on reports from other soybean-producing states, including some adjacent to Illinois, there may be as many as 10 different viruses in Illinois.

Viruses are very simple pathogens, unlike bacteria, fungi, and nematodes that infect soybean, because they are macromolecular particles composed of either ribo- or deoxyribonucleic acid (RNA or DNA) surrounded by a protective protein or lipoprotein coat. Viruses with common characteristics, such as molecular similarity, are grouped together into families. Plant viruses generally are named for the original host from which the virus was isolated or by a major crop that it affects, followed by a descriptor of a distinctive symptom caused by the virus.

Viruses exist as obligate parasites and live only within certain living cells. Most viruses are transmitted from healthy to infected plants by insect vectors. Only a few viruses are transmitted by nematodes and fungi. Many viruses are transmitted through seeds harvested from virus-infected plants. Symptoms caused by viral infection include stunting, mosaic patterns on leaves, yellowing or reddening of foliage, and necrosis of leaves or stems. Some infections are latent and cause no symptoms. Identifying viral diseases in the field based on symptoms is difficult because symptom expression is the result of environmental factors and the genetic diversity and interaction of the host and virus.

Viruses in Illinois

Only a few viruses have been well documented in Illinois. In some areas, certain viruses apparently have reached epidemic proportions, causing yield reductions and associated production problems, including green stem and seed discoloration. In recent years, mild winters resulted in greater vector populations; for example, bean leaf beetles that transmit **bean pod mottle virus (BPMV)**. Another common virus in the state that is transmitted by aphids is **soybean mosaic virus (SMV)**. Both are primary viruses in the state and because of their importance each is covered in its own section in this article. There are other diseases caused by viruses that have been reported in Illinois, but they occur less frequently and their importance or distribution in the state is not known: **cowpea severe mosaic virus (CPSMV), peanut stunt virus (PSV), and tobacco ring spot virus (TRSV)**.

CPSMV has been isolated from soybean showing severe mosaic and stunting. The virus is restricted primarily to legumes. CPSMV is transmitted by a number of different leaf-feeding beetles. The virus is seed-transmitted in cowpea, but not in soybean. This virus may not be a threat to soybean unless it is grown near infected hosts. The virus was isolated from soybean and hoary tick clover (*Desmodium canescens*) in Illinois and reported in 1978

Table 1 ■ Soybean viruses reported in Illinois and other soybean viruses not yet reported in the state.

Virus	Vector	Seed transmission	Distribution/host range
Previously reported in Illinois			
Bean pod mottle virus	Bean leaf beetles and other beetles	Less than 1%	Widely distributed/some legumes
Cowpea severe mosaic virus	Beetles	Up to 100%	Not known/some legumes
Soybean mosaic virus	Aphids	Up to 75%	Widely distributed/many legumes and nonlegumes
Tobacco ringspot virus	Thrips, nematodes	Low to high	Not known/many legumes and nonlegumes
Peanut stunt virus	Aphids	Low	Not known/some legumes
Not reported on soybean in Illinois			
Alfalfa mosaic virus	Aphids	Low	Not reported/some legumes
Bean yellow mosaic virus	Aphids	Not reported	Not reported/many legumes
Peanut mottle virus	Aphids	Not reported	Not reported/many legumes
Peanut stripe virus	Aphids	Not reported	Not reported/many legumes
Soybean dwarf virus	Aphids	Not known	Not reported/many legumes and a few nonlegumes
Tobacco streak virus	Thrips (?)	Up to 30%	Not reported/wide host range, includes many common crop plants

(McLaughlin et al. 1978). There has been no additional information about this virus in the state since then.

PSV, originally described in the United States, was reported to infect soybean in Illinois (Milbrath and Tolin 1977). The virus is transmitted nonpersistently by aphids and through seeds. Resistance in soybean has not been reported. The incidence and distribution of this virus in the state are not known.

TRSV causes bud blight of soybean (Allington 1946). Yields of affected plants may be reduced by 25 to 100%. The most striking symptom is the curving of the terminal bud to form a crook. Other buds may later become brown, necrotic, and brittle and fall off at the slightest touch. Adventitious leaf and floral buds may proliferate excessively. The pith of stems and branches may show a brown discoloration, first near the nodes and then throughout the stem. Brown streaks occasionally are observed on petioles and large leaf veins. Pods generally are underdeveloped or aborted. Those that set before infection often develop dark blotches and contain poorly developed seeds. Maturity is often delayed and plants may remain green and stunted past normal harvest dates. Thrips and dagger nematodes are known to transmit TRSV at a low frequency (Bergeson et al. 1964). Seed transmission is the most important mode of long-range dissemination and carryover from season to season. A few soybean genotypes have resistance to a few strains of TRSV. One genotype (PI 407287) of the annual ancestor of soybean (*Glycine soja*) is resistant to the virus. Other resistant plant introductions (PIs) are 92713 and 154194 (Orellana 1981). We have found this virus every year for the past 5 years in the state, but its overall incidence and distribution are not known.

A potentially complicating factor that may increase the incidence of soybean virus diseases in Illinois is the recent movement of the soybean aphid (*Aphis glycines*) from Wisconsin into Illinois. The aphids were first found in August 2000 colonizing soybean plants in northern Illinois. Since that initial observation, the aphids were found in most Illinois counties, including those in the southern tip of the state before the end of the season, and subsequently soybean aphids were reported in Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, and Ohio. With the introduction of the soybean aphid, the only aphid species known to colonize soybean, there is much greater potential for viruses to become problematic. The presence of the aphid could result in more frequent movement of viruses from plant to plant, and more rapid increase and widespread distribution of viral infections. In particular, there could be an increase in aphid-transmitted viruses that are already known in the state, such as PSV and SMV. In addition, other aphid-transmitted viruses not reported in Illinois, but in soybean-growing areas in the United States, include **alfalfa mosaic**

virus (AMV), **bean yellow mosaic virus**, **peanut mottle virus**, **peanut stripe virus**, and **soybean dwarf virus** (SbDV). In preliminary studies conducted in 2000, SbDV was found to infect clover plants in Illinois. Another factor, perhaps even be more important than the potential widespread distribution of the viruses just mentioned, would be the potential widespread distribution of SMV vectored by the aphid in conjunction with the already widespread distribution of BPMV vectored by bean leaf beetle. When both viruses infect the same plant, the severity of symptoms increases and yields are reduced compared with plants infected singly by either virus (Ross 1968, 1969).

BPMV

BPMV is beetle-transmitted and causes a mottling of soybean leaves. This virus is widespread in the United States. Estimates of yield reductions based on comparison of field-inoculated with noninoculated plants demonstrated that BPMV reduced yields by 3 to 52% (Hopkins and Mueller 1984). The disease decreases pod formation and reduces seed size, weight, and number. When BPMV occurs with SMV infection, severe symptoms occur, causing yield losses to exceed 60% (Ross 1968, 1969). BPMV was first reported in Illinois in 1975 (Milbrath et al. 1975). It now occurs statewide.

Symptoms ■ Symptoms are most obvious in plants infected early in the growing season. Young leaves in the upper canopy exhibit green-to-yellow mottling and severe strains of the virus may cause puckering and distortion of leaves. Symptoms are masked during periods of high temperature and are not observed on plants after pod set. Stems of infected plants with BPMV may remain green after the pods have matured and may retain petioles after leaf blades have abscised (Schwenk and Nickell 1980).

Strains and Host Range ■ There are some known differences in strains of BPMV, including a range from mild-to-severe symptom-causing strains. The host range primarily is restricted to legumes, including beans.

Vectors and Epidemiology ■ Leaf-feeding beetles, such as the spotted cucumber beetle, grape colaspis, striped blister beetle, and the bean leaf beetle (*Cerotoma trifurcata*) transmit BPMV (Gergerich 1999). Bean leaf beetle transmits BPMV efficiently for several days after acquisition from infected plants and is the most important vector in the field. The relationship of BPMV with beetle vectors is typical of beetle-transmitted viruses in that the beetle acquires virus at the initiation of feeding and can transmit the virus immediately without a latent period. In addition, we have shown that the western corn rootworm is a vector of BPMV, at least experimentally.

In the spring, bean leaf beetles feed on infected plants (weedy legumes) or seedborne infected soybean, acquiring the virus and transmitting it to healthy soybean. The virus has been reported to be seed-transmitted in soybean at a frequency of 0.1% (Lin and Hill 1983). Further movement of the virus is dependent on beetle transmission.

Management ■ One way to control the virus is to reduce the primary inoculum by planting seed free of virus and controlling perennial weeds and vectors that may harbor the virus. Perennial weeds such as *Desmodium canadense* and *D. paniculatum* can act as an overwintering reservoir for BPMV (Walters and Lee 1969). In addition, bean leaf beetle control through the use of insecticides can be important, especially early in the season when virus transmission can be detrimental to younger plants. This strategy may include using a trap crop of early planted soybean along field edges 10 to 14 days before the regular planting to attract and concentrate overwintering beetles and then applying insecticide to kill them. Other management techniques include controlling weeds in fields and adjacent to fields, especially for those weeds known to be alternative hosts for BPMV.

Four soybean germplasm lines were registered as resistant to BPMV in 1986 (Ross 1986). Immunity to BPMV has not been found in soybean. Immunity has been identified in perennial *Glycine* species (Gergerich 1999). It may be possible to introduce immunity to BPMV into commercial cultivars by interspecific crosses.

SMV

SMV, the cause of soybean mosaic, occurs in all soybean production areas of the world. Yield reductions range from 8 to 35%, although higher losses have been reported (Hill et al. 1987). Early SMV infection reduces pod set and seed quality traits, including seed size, weights, and increased seed coat mottling. Late-season infection has little effect on seed quality and yield.

Symptoms ■ Symptoms of infected plants vary with genotype, virus strain, plant age at infection, and environment. Infected plants are usually slightly stunted with fewer pods. Leaves have a mosaic of light and dark green areas that may later become raised or blistered, particularly along the main veins. Leaf margins may curl downward. Some strains can induce severe stunting; systemic necrosis; leaf yellowing; petiole and stem necrosis; terminal necrosis; and defoliation, usually leading to death.

Strains and Host Range ■ Strains are grouped according to symptoms produced on a differential soybean set. Numerous strains of the virus have been identified using eight soybean lines. The strains are currently known as G1 through G7, G7a, and C14 (Cho and Goodman 1979). The most economically important host is soybean. SMV is limited to other hosts in six plant families, most of which are in the Fabaceae or bean family.

Vectors and Epidemiology ■ At least 32 aphid species, belonging to 15 different genera, transmit the virus in a nonpersistent manner (Hill 1999). Virus isolates may show some vector specificity. With the recent introduction of the soybean aphid, there may be more frequent movement of viruses from plant to plant, and thus potentially very rapid increase and widespread distribution of SMV. We are currently working on SMV strain specificity to the soybean aphid.

Infected plants resulting from transmission through seed serve as a primary inoculum source for SMV (Kendrick and Gardner 1924, Bowers and Goodman 1979). The spread within and among fields is mostly aggregated from a point source with secondary spread by aphids. Virus in seeds remains infective for a long time and viable virus can be recovered from seeds that no longer germinate. The level of seed transmission is dependent upon soybean genotype and time of infection with the incidence of seed transmission higher in plants infected before the onset of flowering.

Management ■ The production and use of SMV-free seed is one of the best control measures. Serological seed indexing techniques and grow-out tests can be used for detection of virus in seed lots. Insecticidal control of aphids is nearly impossible for aphids that do not colonize soybean because they reside in plants other than soybean. Insecticidal control of the soybean aphid will be most important and effective because it can colonize the soybean plant. This may be the first step in reducing aphid-transmitted viruses.

Several sources of resistance to SMV have been reported (Hill 1999). The first dominant resistance gene identified in soybean was from PI 96983 and was designated *Rsv1*. Single resistance genes in other genotypes, which confer differential reactions to strains G1 to G7, were found to be alleles at the *Rsv*1 locus and have been designated as *Rsv1y*, *Rsv1m*, *Rsv1t*, *Rsv1k*, *Rsv1s*, and *Rsv1n*. Subsequently, *Rsv*3 and probably *Rsv4* have been assigned to resistance loci independent of the *Rsv*1 locus. Many of these sources of resistance have been used to develop varieties in the southern United States, but not in the north.

Future Research

Systematic surveys for soybean-infecting viruses have not been conducted in Illinois. Preliminary data from 2000 indicate that BPMV is widespread with some SMV occurring at lower incidences. There is little known about the incidence and distribution of other viruses, although CPSMV, TRSV, and PSV have been reported in Illinois. A statewide systematic survey for soybean viruses has been initiated. In addition, a survey for soybean insects, including the spread of rotation-resistant western corn rootworm, the abundance of northern corn rootworm, southern corn rootworm, Japanese beetle, bean leaf beetle, grape colaspis, and the soybean aphid was conducted in summer 2000 with results pending. Soybean plant material collected from these same fields will provide information on the severity and distribution of viruses in the state.

In addition to the research being conducted in Illinois, there is additional support from scientists throughout the North Central region where several specific areas of research are being investigated. One area is on virus strain diversity, specifically with BPMV, which includes genomic diversity among virus isolates and pathological differences among strains. Another area of cooperative research is disease identification, which includes development of rapid, sensitive detection and diagnostic techniques for AMV, BPMV, TSV, and SMV. These techniques will enable systematic surveys in states to identity the viruses and determine their distribution. Research also will be conducted to establish the association among field symptoms (green stem and top necrosis syndrome) to specific viruses and

combinations of viruses. Additional research will determine and differentiate symptoms caused by the soybean aphid and viruses that may be transmitted by the aphid.

Management of virus diseases must include chemical, cultural, and host resistance strategies. For chemical controls, testing and implementation of spray schedules for insecticides that are registered for control of the bean leaf beetle (Warrior), plus testing of other compounds, such as Gaucho and Adage (both systemic seed treatments) are needed. Other compounds need to be tested for the control of the soybean aphid. For cultural practices, delayed planting may avoid initial peak populations of the bean leaf beetle and reduce yield loss associated with early infection of soybean plants. Row width may influence populations of potential insect vectors.

Host resistance to the viruses or their vectors is an important component of management. There has been some initial screening of soybean varieties in the Illinois Soybean Variety Testing program for symptoms of green stem. Additional research is underway to evaluate some of these varieties for resistance to BPMV. Although several sources of resistance were reported for BPMV (Ross 1986), more sources of resistance are needed to allow for further development of resistant germplasm. For SMV, although genes for resistance have been characterized, these resistance genes need to be incorporated into northern elite breeding lines. For other viruses, such as AMV, TRSV, and TSV, once sources of resistance have been verified for these viruses, these resistant sources will be incorporated into the elite germplasm for release to commercial breeding programs.

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Seed Treatments for Soybean, Corn, and Wheat

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Corn

Fungicide seed treatments have been used on most seed corn hybrids and inbreds for many years. In first half of the 20th century, organic mercury compounds were commonly used on cereal crops, and they were very effective. However, the mercury compounds were a significant threat to the environment and were banned in the United States. In the 1950s, captan replaced the mercury compounds and remained the standard fungicide seed treatment on corn until the 1990s. The first major change occurred when metalaxyl was added to captan to reduce stand reductions caused by the water mold fungus *Pythium*. The increase in disease pressure was a result of growers planting earlier than in the past and using more reduced-tillage methods, especially no-till. Within a few years, most of the seed companies were adding metalaxyl to their standard treatment of captan. Recently, Novartis developed a new formulation of Apron XL, and the active ingredient is mefenoxam. However, the original formulation of metalaxyl is still available from Gustafson, but is now called Allegiance. Over the past several years, many new products have been introduced. The most successful is Maxim (fludioxonil, manufactured by Novartis). It controls most of the same soilborne and seedborne plant pathogens as captan, but it is applied at a much lower rate (25 ppm compared with approximately 550–750 ppm). The two most common seed treatments on corn are Maxim + Apron XL and Captan + Allegiance.

Table 1 ■ Fungicide seed treatments for corn, South Farms, Urbana, 2000.

Treatment	Plant stand (plants/acre)	Yield (bu/acre)
Untreated control	21,315	131.2
Captan + Allegiance	23,551	141.2
Maxim + Apron XL(normal rate)	24,466	143.3
Maxim + Apron XL (high rate)	25,192	145.2
Maxim + Allegiance	25,250	145.8
Maxim + Apron XL + Gaucho	25,700	156.7
LSD (10%)	2,844	8.5

Hybrid tested, Pioneer 33A14 (warm germination 96%, cold germination 92%); planting date, April 14, 2000; planting population, 28,500 seeds/acre; stand counts, May 21, 2000; harvest date, October 13, 2000.

Recently, there has been an increased interest in seed treatment insecticides. Gustafson introduced Gaucho and Prescribe, both of which contain imidacloprid, and they are being promoted for use on the 2001 crop. Information is available about the control of rootworms by both products from John Shaw (Center for Economic Entomology, Illinois Natural History Survey), and Kevin Steffey and Mike Gray (Department of Crop Sciences, University of Illinois). We evaluated Gaucho in 2000 (Table 1) and observed a yield benefit for the Maxim + Apron XL + Gaucho treatment compared with the Maxim + Apron XL treatment. However, all of our plots were treated with the soil insecticide Force (Zeneca), and we did not evaluate rootworm feeding in any of our trials. Therefore, we cannot attribute the yield benefit to any specific parameter.

Table 2 ■ Fungicide seed treatments for soybean, South Farms, Urbana, 2000.

Treatments	Plant stand (plants/acre)	Yield (bu/acre)
Untreated control	90,024	43.3
Rival + Allegiance	148,104	48.6
Maxim + Apron XL	152,823	49.2
LSD (10%)	12,355	3.1

Cultivar tested, Pioneer Brand 93B01; planted population, 200,000 seeds/acre in 30-inch rows (White 6100 planter); tillage, no-till; planted, May 3, 2000; stand count, June 8, 2000; harvest date, October 6, 2000; herbicide, Roundup applied at planting and 28 days after planting.

Table 3 ■ Fungicide seed treatments for wheat, South Farms, Urbana, 1999 and 2000.

Treatments	Plant stand (plants/acre)	Yield (bu/acre)
Untreated control	714,000	74.1
Raxil + Thiram	1,001,000	79.4
Dividend XL	1,049,000	80.1
Raxil XT WP	1,020,000	78.2
Raxil XT WP + Gaucho 480	1,051,000	80.3
LSD (10%)	128,000	3.2

Cultivar tested, Kaskaskia (University of Illinois) (warm germination 94%); seeding rate, 1,200,000 viable seeds/acre under no-till following corn; planting date, October 3, 1999; stand counts, April 22, 2000; harvesting date, June 27, 2000.

Soybean

Unlike corn, relatively few bushels of soybean are treated with fungicide seed treatments. Traditionally, soybean are planted or drilled after corn has been planted, so the soil temperatures are warmer. Hence, germination can be rapid and plant pathogens may not be as important. In addition, soybean plants have a tremendous ability to compensate for missing plants. Finally, many companies have been reluctant to provide fungicide seed treatments because of the difficulty of managing inventory. Unlike corn that can be stored for at least 3 years without notable loss in germination, soybean seeds that are treated must be planted that year. Any remaining treated soybean seed must be disposed of in an approved method. Discovery of just one treated seed in a truckload of soybean can result in the soybean being rejected at market.

Recently, growers have begun to plant soybean earlier, just as they are planting corn earlier, and a high percentage is planted or drilled into fields in which some form of conservation tillage is practiced. In addition, soybean seed costs have increased. Therefore, interest in fungicide seed treatments on soybean has increased. Currently, there are two major combinations of fungicides for soybean: Maxim + Apron XL and Rival + Allegiance. Rival is a combination of captan + TBZ and PCNB; the other products are the same as was described for corn. Table 2 is a summary of the evaluations of fungicide seed treatments on soybean in 2000.

Wheat

The use of fungicide seed treatments on wheat is similar to the use of seed treatments on soybean. There are several good fungicide seed treatments available, but a large percentage of the wheat is not treated. Soil temperatures at planting in the fall are generally warmer than they are in the spring; hence, many plant pathogens may not cause significant stand reductions. However, a high percentage of certified seed is treated, primarily to ensure very low levels of loose smut, *Ustilago tritici*, as well as uniform stands. In 2000, we evaluated a number of seed treatments, including Raxil (active ingredient tebuconazole), Thiram, and Dividend (active ingredient difenoconazole) (Table 3). We also evaluated the insecticide Gaucho, in combination with Raxil, on wheat. Plant stands (determined in the spring) and yield were significantly higher than corresponding measurements in the control. We observed no significant differences in plant stands and yields among the different fungicide treatments.

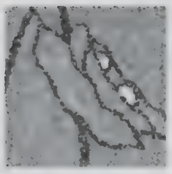
Digital Imaging: Get the Picture

Dennis Bowman and Robert Bellm

Digital cameras are becoming a standard crop-scouting tool. Images of plant and pest problems can be sent over the Internet very quickly to experts around the world for diagnostic assistance. This speed of diagnosis may result in a more timely pest management decision that may save crop quantity and quality. Sending digital images over the Internet also saves the frustration of mailing a sample and finding out that by the time it reached its destination it had deteriorated beyond the point of recognition.

The accuracy of a diagnosis from images is directly related to the quality of the images. Both the photographic quality and the image content are important. Focus, framing, and lighting are some characteristics of photo quality. With a little practice, almost anyone can take pretty pictures with today's digital cameras.

For an accurate and fast diagnosis, the correct content in the images is necessary. The correct range of images is also critical. From shots of the field that show patterns to close-ups of specific anatomical structures, a series of pictures gives the diagnostician the best information about the situation. Insects, weeds, and plant disease all have different sets of characteristics that are critical for diagnosis. This workshop covers some of the characteristics for facilitating a rapid and accurate diagnosis.



Management, Organic Matter, and Carbon Sequestration

Michelle Wander

Carbon dioxide (CO_2) is accumulating in the atmosphere at a rate of 3.5 billion metric tons per year and this increase is expected to cause observable shifts in climate in this century. If ratified, the 1997 Kyoto Protocol to the United Nations Framework Convention on Climate Change would require developed nations to reduce their emissions of greenhouse gases during the period 2008–2012 to pre-1990 levels. Strategies for reductions include reduced emissions of several greenhouse gases and net removal of CO_2. Unfortunately, the protocol did not adequately specify how changes in land management might be used by countries to satisfy their reduction commitments. It is clear that agricultural soils could sequester significant amounts of CO_2. Many sources suggest that over the next 50–100 years, the world's agricultural soils could remove 40–80 billion metric tons of carbon from the atmosphere. The agricultural soils of the United States might sequester 17–39 metric tons of carbon per year (Lal et al. 1998). The potentially large initial contribution of soils to emission reductions has actually caused some to oppose the use of agricultural and forested lands in Kyoto Protocol calculations. Critics fear that annual accumulation of carbon (C) in agricultural soils, which might be partially achieved by accounting of previously undocumented stocks, could be large enough to greatly diminish the impact of the accord on energy-related emissions. Concerns also have been raised about 1) the uncertainty of benefits accrued to specific land management practices, 2) our capacity to evaluate or verify outcomes in a timely and affordable manner, and 3) the limited amount of information relating C sequestration to associated environmental impacts.

The potential for C sequestration in agricultural lands has not only been discussed at the policy level. Farmer interest in soil organic matter management and C sequestration has grown rapidly during the past few years due to the prospect they might receive payments for C credits. In 1996, Canadian energy firms established the Greenhouse Emissions Management Consortium (GEMCo) to develop commercial mechanisms for trading agricultural C credits. One of their stated goals was to invest in sustainable land management practices that enhance the C content of soils in the medium term and the viability of farms in the long term. This investment became relevant to Illinois farmers when the Iowa-based IGF Crop Insurance Company agreed to broker C emission reduction credits (CERCs) for GEMCo. A CERC, the equivalent of 1 metric ton of atmospheric CO_2 reduced or avoided from an agreed baseline, can be generated by documenting activities that provide a net "sink" or actual reduction of emissions by avoidance or substitution. Once created, CERCs do not expire or exhaust themselves, i.e., sequestered C should be committed to a permanent sink. The CERCs are awarded for agricultural practices such as minimum-till and no-till farming practices, cropland retirement, buffer strips, afforestation, reforestation, improved timber management, power generation from biomass, and methane abatement from livestock waste.

It is vital that we are not too far off in our estimations for soil C storage potential. Experts agree that at present we do not have models with the predictive capacity to estimate C flux across the gradient of management and soil conditions needed. Many of

Table 1 ■ Nitrogen fertility, crop rotation, yield, and changes in coil C storage [data abstracted from Vanotti et al. (1997)].

Nitrogen[1] treatment kg ha^{-1}	Rotation	Corn yield kg ha^{-1}	Residue returned t ha^{-1}	Change in organic C g C kg^{-1}	Rate of change g C kg^{-1} yr^{-1}
Arlington					
0	CC	3,760	67	0.040816	0.001633
84	CC	6,632	91	0.145455	0.005818
168	CC	7,047	94	0.153153	0.006126
Lancaster					
0	CC	3,261	56	–0.15	–0.00682
84	CC	6,106	76	–0.31967	–0.01453
168	CC	6,920	82	–0.18382	–0.00836
336	CC	7,447	86	–0.21053	–0.00957
0	CCOAA	7,000	ND	0.01227	0.000558
0	CSOA	7,900	ND	0.006173	0.000281
0	AC	8,000	ND	–0.05229	–0.00238

[1] Experiment had been in place for 25 years in Arlington and 22 years at Lancaster. CC is continuous corn; CCOAA is corn, corn, oats and two years of alfalfa; CSOA is corn, oats, soybean, and alfalfa; and AC denotes an alfalfa corn rotation.

the projections for C sequestration by agricultural soils have used yield trends as inputs to drive empirical models to predict future soil C stocks (Donigan et al. 1995). Use of yield trends and not actual trends in C stocks as a basis for prediction is a serious deficiency in these models. The influence of cropping practices on soil C content depends on many factors, including the condition of the soil being managed. Results from a long-term study conducted at two sites in Wisconsin can be used to demonstrate several important points (Table 1).

In both sites in the continuous corn (CC) plots, corn yield and the amount of crop residue returned to the soil increased with nitrogen (N) application rate. At the Lancaster site, corn yield in rotation plots that included alfalfa equaled or exceeded the highest yield obtained in the CC plots without fertilizer N application. At the Arlington site, increases in organic C contents were positively related to residue return rates. In similarly managed CC plots at the Lancaster site, organic C was actually lost from all plots, and the magnitude of that loss was not diminished by increasing amounts of residue returned. Organic C also was lost from that site in the alfalfa–corn (AC) rotation plots; only the CCOAA and CSOA plots accumulated C during the 22-year trial. The Arlington and Lancaster sites did not differ in their responsiveness to management because of the quantity of organic C they contained at the start of the experiment; the soil at the Arlington site was a mollisol that had a C content of 18.8 g kg^{-1} soil, and at the Lancaster site the soil was an alfisol with a C content of 16.1 g kg^{-1} soil. It may be that the soil at the Lancaster site was at or near its saturation capacity for organic C and that the quality of the organic matter was very high because that site had been in alfalfa–bromegrass pasture before the experiment was begun.

Because of this uncertainty, some have cited a need for assessment and validation techniques, whereas others argue against farm- or field-level sampling, citing the high cost of on-site soil C monitoring. Beyond cost limitations, there are several practical factors that limit the usefulness of soil sampling in the short term as basis for program success. The first problem is that it may take a decade or more before changes in soil organic C contents become apparent. A second problem is that farmers who participate in programs do not control all of the factors influencing C balance in their soils. A catastrophic flood or prolonged drought could offset or totally undermine any improvements to soil C balance, despite a farmer's use of best management practices. Should a farmer who adopted all the recommended practices be rewarded on the basis of how much C he or she sequesters or regardless of the outcome? During the early stages of a C credit program, it is most likely that producers will be rewarded based on probable rather than actual outcomes.

What are the probable outcomes for soil C sequestration? To estimate what might be expected for Midwest soils, I summarized long-term studies from Corn Belt states that recorded the influence of management practices on soil organic carbon (SOC) concentrations in the top 20–30-cm depth (Table 2). The SOC concentrations of conventional treatments (tilled plots with CC or corn and soybean grown in rotation) were the controls used as denominators

Table 2 ■ Soil Carbon Sequestration Potential in the Midwest.

Cropping system	C sequestration potential kg C ha^{-1} yr^{-1}
Conventional continuous corn	0
No-till continuous corn	116
Diversified rotation: C–S–W, fertilizer based	203
Diversified rotation: C–S–W, manure based	791
Diversified rotation: C–S–W, legume based	998
Diversified rotation/reduced tillage: C–S–W, legume based	3029

C–S–W, corn–soy–wheat.

From Dick et al. (1991), Robinson et al. (1996), Lesong and Doran (1997), Paustian et al. (1997), Vanotti et al. (1997), Aref and Wander (1998), Hussain et al. (1999), Lal et al. (1998), Wander et al. (1998), Drinkwater et al. (1999).

against which SOC contents of soils under alternate management were compared. For all treatment categories, the mean percentage change in SOC was computed; this value was then divided by the mean duration of the experimental trials that were compared (%$change_{no\text{-}till}$/years $under_{no\text{-}till}$). The resulting rates of change were converted to an area basis by multiplying these values by the SOC control concentration and then converting g C kg^{-1} soil $year^{-1}$ (to 20-cm depth) to kg C ha^{-1} $year^{-1}$ by multiplying by 2,900 for tilled treatments or 2,940 for no-till treatments.

This summary suggests that adoption of reduced or no-till practices increases C sequestration rates compared with tilled soils and that diversification of cropping systems increases sequestration potential even more. Data from the region suggest that cropping systems that substitute organic sources of fertility or reduce tillage in a diversified cropping system have the potential to sequester C at very high rates. This summary suggests that in this region, cropping system diversification should be considered at least as important as tillage reduction for CO_2 abatement.

There are several issues that will determine whether C credits are awarded to producers for altering their agronomic practices. Resolution of article 3.4 of the Kyoto Protocol to determine whether and how C sequestered in agricultural lands can be deducted from emission reduction commitments will be critical. If agricultural C sinks are approved, then scientists and economists will need to work hard to avoid pressures to accept politically expedient solutions that will not lead to actual reductions in greenhouse gas emissions and CO_2 levels. In the future, documentation of benefits of soil C sequestration to soil and crop quality, water quality, wildlife habitat, and cropping system efficiency would help build lasting public support for this kind of program. Ultimately, strategic sampling protocols will be needed to improve and demonstrate the success of C credit programs.

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Herbicide Behavior in the Soil Environment

Bill Simmons

Herbicides with soil activity are still an important component of weed control in corn and soybean, and they include both PRE- and POST-applied herbicides. The interaction of soil properties, water, and application timing affects the efficacy, crop response, and potential for carryover. This article discusses four topics: 1) the basics of soil interactions with herbicides; 2) efficacy of fall-applied herbicides; 3) carryover potential as affected by herbicide, soil, and climatic conditions; and 4) the value of residual control in total POST systems.

Soils contain organic matter and clay particles that control herbicide sorption and water relations, and provide an environment that influences microbial activity. The two primary herbicide loss pathways in soil are microbial and chemical breakdown, both mainly driven by reactions with water. The effects of soil temperature and moisture on herbicide degradation are straightforward in that degradation mechanisms that involve microorganisms operate best at optimum biological growth conditions. In addition, nonbiological chemical reactions typically are enhanced under optimum conditions such as increased temperature. Water is essential for microbial activity and increases aerobic processes until saturation occurs and gas transfer with the atmosphere is hampered.

Soil texture and organic matter content have a surprisingly small effect on carryover because the differences in water and nutrient availability often are counterbalanced by differences in herbicide adsorption. Thus, a fertile soil, rich in organic matter, may not only promote faster degradation of a herbicide but also have less herbicide available to degrade because of its greater number of adsorption sites.

Soil pH affects the stability of some herbicides and herbicide families. High soil pH associated with calcitic soils, over-liming, or proximity to limestone gravel lanes may reduce herbicide degradation and increase carryover. These effects may be important for triazines and some sulfonylureas. Hydrolysis, an important breakdown mechanism, slows significantly at soil pH values near 7.0.

Biopersistence, or the ability of the parent compound to exist in the soil, is an important feature of soil-applied and some postemergence herbicides and determines the suitability of early preplant applications, residual weed control, and threat of off-site loss to surface or groundwater. To optimize the application timing of soil-applied herbicides, a balance between persistence and requirement for rainfall needs to be considered.

The soil-applied acetamide market in corn is still a significant and competitive marketplace where performance profiles across application timings determine use and market share. In the last few years two new herbicides have been introduced—Axiom (flufenacet and metribuzin) by Bayer Corporation and, most recently, Degree (formerly MON 58430, encapsulated acetochlor) by Monsanto. Dual Magnum is the active isomer of metolachlor and allows for a lower use rate than the "old" Dual. BASF also has purified an active isomer of dimethenamid (Frontier/Outlook) that allows its use rate to be lowered while obtaining the same efficacy. These herbicides are the most recent to enter the marketplace. Changes in the use patterns of these herbi-

cides may occur in transgenic corn, in mixes with isoxaflutole and similar herbicides, and in formulations that allow POST application.

Persistence is an important property of soil-applied herbicides and some postemergence herbicides because it allows for extended weed control. When a herbicide remains unaltered in the soil during the crop season of application, it is an advantage. However, if a herbicide remains in the soil and is present when a rotational (and susceptible) crop is planted, persistence leads to herbicide carryover. Most herbicides do not carryover. Degradation rates in the soil under normal environmental conditions typically reduce herbicide concentrations to sublethal levels for rotational crops. Some herbicides are also safe because they are not injurious to rotational crops.

Shifts in herbicide application timing to earlier applications have put a premium on herbicide persistence to coincide with weed emergence. In a broad sense, the resistance to degradation and downward movement within the soil profile are both important to obtaining satisfactory weed control.

Persistence is an important characteristic of a herbicide because it affects efficacy, exposure to environmentally important transport, and carryover to subsequent crops. Persistence is the integrated result of all herbicide loss pathways that act upon the parent compound when it is in the soil environment.

Degradation of many herbicides follows first order kinetics, thus the rate of degradation is roughly proportional to the herbicide concentration. The half-life, or time when 50% of the parent compound is gone, is a herbicide property that is frequently cited in technical information and promotional literature. Under field conditions, the half-life is variable and depends upon environmental conditions.

Glyphosate-resistant soybean treated with glyphosate alone does not allow for any residual control of weeds that might germinate after the last POST application is made. What is the value of a residual herbicide either mixed in with glyphosate or applied to the soil at planting? Data are presented that address this issue. Fun will be had by all!

Plant Stresses in Corn and Soybean

Emerson D. Nafziger

A very common response that many of us give when asked what might be happening with a crop in the field is, "The crop is under stress." Most of us conclude that crops don't experience the psychological stress that humans experience (as far as we know), so what do we mean when we say that plants are "under stress"? This workshop addresses this question and possibly improves the accuracy of our understanding of the term *stress.*

Although there have been reports of electrical signals traveling (like nerve impulses) within plants when various external abuses are applied, plants are not normally considered as "suffering" as the result of stress. Instead, stress in plants is considered to be a shortage of one or more factors needed for optimal growth, resulting in reduced rates of biochemical processes that affect growth and function. The most common shortage is the lack of water. Even where soil water is adequate on a given day, very high evaporative demand (high temperature, low humidity, high sunlight, and windy conditions) can remove water from the leaves more quickly than the plant roots can take up water; thus, the plant experiences water stress, at least during part of the day. Measurements and consequences of water stress are discussed during the workshop.

Other stresses that are common in the field include loss of leaf area and low sunlight intensity, both of which cause decreased photosynthetic capacity, with the shortage considered the supply of photosynthate (sugars and other products produced using light energy) within the plant. Insects and leaf diseases are two common causes of reduced photosynthetic rates. In addition, insects and diseases can cause water shortages in plants by damaging internal tissues. There are also biochemical stresses to plants. They are caused by insect or disease toxins, or by herbicides or other chemicals that directly affect specific enzymes, causing shortages of substances needed for optimal growth.

Although it is easy to describe a variety of plant problems as being due to stress, it is difficult to predict with certainty what effect stress might have on plants. Losses of photosynthetic capacity (e.g., leaf loss due to hail) are known to affect grain yield differently, depending on when during the season that the stress-causing event occurs. Water shortages are known to decrease yield, but mild shortages at some times during the growing season can increase yield. These water shortages may cause roots to grow deeper or may boost yields indirectly, for example, when the high sunlight that usually accompanies dry weather improves photosynthetic rates more than the dry weather inhibits them. However, the "stress on stress" phenomenon, in which combined stresses might cause more damage or yield loss than if the stresses were simply additive, also occurs.

Although it is difficult to measure most stresses directly and to predict the effect of stresses on yield, it is possible to better understand sources of stress, how different stresses affect plants, and how some stresses might be managed.

Tough Weeds on the Horizon—Know Them and Attack Them

Jerry Doll

Mother Nature seems to never sleep. If we use the same crop production system for many years, she responds with a change in the weed spectrum. And if we change from one tillage system to another, again the weed complex changes. This workshop describes some of the weeds on the increase in Wisconsin cropping systems. Many are probably occurring in Illinois as well.

Wild Four O'clock
(Myrabilis nyctaginea)

This taprooted perennial is native to the United States. It has spread from its home in the southwest along rail and highway corridors and now stretches from Texas to Maryland. We first received reports of it in no-till fields, but in recent years it is just as common in chisel plowed and other reduced tillage systems. Plants thrive in shallow, gravelly soils (thus, its frequency in rail and highway systems) but are probably able to grow and compete in many soil types. When plants grow undisturbed, roots can be 2.5 to 3 inches in diameter. Wild four o'clock is a prolific seed producer. Seeds germinate in early May and seedlings appear well into the growing season. Emergence from roots occurs over an extended period as well. Little additional information on the biology of wild four o'clock is available.

Plants are easily identified. Weed books describe the roots as fleshy, but they seem to be somewhat woody under Wisconsin conditions. Plants grow 2 to more than 3 feet in height and have erect, branched stems with conspicuous nodes that are particularly evident after leaf drop. Stems are often four-sided but are not as square as those of plants in the mint family. Leaves are opposite, simple, heart-shaped (resemble a lilac leaf), and 1 to 3 inches in length, usually with a pointed tip. Leaves have a short petiole and are widely separated on the stem. The inflorescence is an umbel of terminal clusters, each cluster with one to five flowers. Individual flowers are perfect, have no petals and are bell-shaped with pink-to-reddish purple sepals (calyx). Seeds are oblong, grayish brown to yellow, and warty or wrinkled with five ribs that are approximately 3/16 inch in length. The large, tough taproot; the opposite lilac-like leaves; branched, squarish stems; and pink-to-reddish flowers that open in the late afternoon and close in the late morning easily distinguish wild four-o'clock from other plants.

Wirestem Muhly
(Muhlenbergia frondosa)

Wirestem muhly weed is also native to North America. It has generally remained on the fringe of agricultural systems, with rather limited appearances as a significant weed problem. The *Muhlenbergia* genus contains more than 50 species in the United States, but wirestem muhly is the only one of agricultural significance. A 1960 article labeled wirestem muhly as "a new cornfield weed menace" (Scott and Slife 1960) and alerted producers in the upper Midwest of the potential problem. Little changed for the next 20 years, but since the mid-1980s, wirestem muhly has invaded new areas and has increased in frequency and density where it already existed.

The increased abundance of wirestem muhly is due to several factors, including the adoption of reduced tillage systems, excellent control of other weed species, loss of diversity in crop rotations (especially less forages), and the production and spread of wirestem muhly seeds.

Wirestem muhly can be easily confused with quackgrass because both are perennial grasses with rhizomes. However, there are notable differences between them (Table 1).

The top-heavy appearance of wirestem muhly plants is due to branches formed in the upper nodes and to upper internodes being shorter than lower internodes. The stems are erect early but often become decumbent and can form roots at the nodes. The inflorescence is a panicle, and plants produce numerous axillary infloresences, many of which are enclosed in the leaf sheaths. The main stem and all tillers form seed heads, giving plants a tremendous seed production potential.

Comfrey (Symphytum officinale)

Comfrey is native to Russia and was introduced into the United States from Europe as a medicinal herb. It also has been used as a forage crop. Medicinal and herbal tea uses have come into disfavor because the plant contains alkaloids that can cause serious health problems if consumed in excess or over long periods. Once established, comfrey is very difficult to eradicate. Our infestations are most often the result of a garden being converted into a field. The shift from moldboard plows and disks to chisel plows and tined secondary tillage tools has undoubtedly spread comfrey roots from their original sites.

Plants are 2 to 4 feet in height and have many large, dark green, hairy leaves that arise from the crown and feel somewhat sticky. Leaves are up to 8 inches in length, have no petioles, and flow into the stem, giving it a winged appearance. Comfrey flowers are bell-like, blue, pinkish, or white and are borne in one-sided clusters on curved stalks, as is typical of plants in the Borage family. A pair of wing-like leaves is present at the base of each flower stalk. Plants seldom produce viable seed but have many thick, branched, brownish-to-black taproots that can reach 9 feet in depth. Plants propagate readily from root fragments. Little is known about the biology of comfrey under field conditions.

Table 1 ■ Comparison of the key characteristics of quackgrass and wirestem muhly.

Characteristic	Quackgrass	Wirestem muhly
Grass type	Cool season, C_3	Warm season, C_4
Auricles	Present	None
Membranous ligule	Very short	Easily seen
Leaves	Few	Numerous, narrow
Tillers	Few	Numerous
Rhizomes	Long, slender, smooth	Thick, short, scaly

Giant chickweed (Myosoton aquaticum)

Giant chickweed is native to Europe. The species name suggests plants grow in wet habits, but giant chickweed was first observed in upland pastures of southwestern Wisconsin in the early 1980s. Since then, it has spread to many areas of the state and in recent years has been a weed of concern in numerous pastures, hayfields, and several cropped sites. Once established, plants spread by the semiprostrate stems and seed. Patches of giant chickweed quickly dominate pasture species by shading. Livestock seem to avoid feeding on giant chickweed, allowing the weed to spread and produce seed abundantly.

Leaves are larger than those of mouse-ear and common chickweed. They are opposite and have no petioles. Stems are angled, tend to grow horizontally before becoming erect, and reach heights of 8 to 12 inches. Typical of many plants in the Pink (chickweed) family, the five petals are split, giving the appearance of having 10 petals. Fruits are borne on short stalks that bend downward when mature, and the stalks are covered with hairs that exude a sticky juice.

Hemp dogbane (Apocynum cannabinum)

Hemp dogbane is another weed native to North America. It has an extensive vertical and horizontal rhizome system and managing hemp dogbane is complicated by its extended period of emergence. Hemp dogbane is capable of reproducing by seed, but nearly all plants in cultivated fields arise from vegetative buds in the crown region and on the

horizontal lateral roots. All plant parts have sticky, milky sap, thus dogbane may be confused with common milkweed in the vegetative stage.

Hemp dogbane has an extensive, branched root system with vegetative buds irregularly placed on the lateral roots. The buds can give rise to shoots, but most remain dormant. Vertical roots may penetrate 8 feet or more but do not have buds. Hemp dogbane stems are reddish and smooth and grow 3 to 5 feet in height. They are woody near the base, and, unlike common milkweed, dogbane stems branch near the top, giving them a "bushy" look. The leaves are smooth, opposite, ovate to lanceolate, and have a very short petiole. They generally are smaller, lighter green, and more pointed than the leaves of common milkweed. Hemp dogbane leaves are bright green during the growing season and turn a yellowish brown to orangish yellow in the fall.

From late June to August, hemp dogbane produces clusters of small, greenish white, bell-shaped flowers at the end of each branch. Each flower may produce two slender, slightly curved, pencil-like pods 3 to 4 inches in length. Pods have up to 200 reddish brown seeds, each with a tuft of silk on one end, similar to milkweed seeds. However, common milkweed seeds are much wider and flatter than hemp dogbane's spike-shaped seeds.

Other Weeds

The above-mentioned weeds are the main focus of the workshop; however, smooth hawksbeard, flixweed, broadleaf plantain, prickly lettuce, purple loosestrife, and garlic mustard also are identified and discussed. Participants are encouraged to share their observations on weeds that they see increasing in Illinois cropping systems.

Identifying New Weeds

Plant identification is both a challenge and a necessity. Even in this era of transgenic crops, accurate records on the weeds present during the season are an essential component of integrated cropping systems. Two new resources are worthy of mention. They contain weeds not always found in other common identification references.

Weeds of the Northeast (Uva et al. 1997) is one of the newest and also one of the best weed identification references. It contains nearly 300 species, some of which are not found in either *Weeds of the North Central States* (Wax et al. 1995) or *Ontario Weeds* (Alex 1992). This book is one of the few to include woody species, which are more common in Conservation Reserve Program (CRP) land and increasing in no-till acreage. The book contains five "short-cut identification tables" that identify weeds with special characteristics and a standard dichotomous key for all species that is based on vegetative characteristics. Each weed has four or more colored pictures; a narrative, including a useful description of how to distinguish it from similar weeds; and line drawings of key characteristics of certain weeds. It is available from Gemplers for $32 plus shipping and handling. To order, call 1-800-382-8473.

Weeds of the Northern United States and Canada (Royer and Dickinson 1999) is dedicated "to farmers everywhere." This book is marketed as a practical reference on how to identify weeds. It contains more than 750 color photographs of 175 weed species. The overall layout of the book is excellent and includes 150 line drawings to complement the color images. What makes this book unique are the 275 small color pictures as "thumbnail" images of plants at the beginning of the book that are part of the weed identification key. The broadleaf identification key is based on leaf arrangement and flower color: nearly 100 species on just four pages! Below the thumbnail photos are the page numbers where the full description of the species is found. The grass identification key has thumbnail images of both the leaf collar and the inflorescence for each species. Also unique are the "quick identification" sections that start the description of each weed. These sections give you three key characteristics of each species. A complete description of all plant parts then follows. The remaining two sections for each weed are "reasons for concern" and "similar species," very helpful information not often found in plant identification references. This resource is available for $21.95 plus $5 for shipping (Canadian dollar prices). The book is published by the University of Alberta Press and is available from Raincoast Books. Call 604-323-7100 to order. They accept major credit cards.

Managing These Weeds

Rather than discuss the impact of tillage, cultivation, rotation, and herbicides on these weeds in this article, I share such information during the workshop. Participants also are invited to relate their experiences in managing these and other new weed species.

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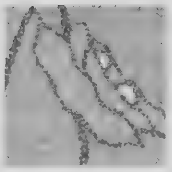

Weed Population Dynamics

Bob Hartzler

The weed infestation in a given field is defined by three main factors: 1) number of species present, 2) density of each species, and 3) distribution of each species across the field. Although the number of species in a field remains relatively constant from year to year, density and distribution fluctuate widely in response to environment, cultural practices, and weed management tactics. It is the continual changes in weed infestations that make successful weed control such a difficult task to achieve.

The weed seed bank in agricultural fields is made up of many species, but in any given year the infestation typically is dominated by a few species. An Illinois field maintained in a corn–soybean rotation was found to have 25 weed species in the seed bank, but only four species accounted for 85% of the weed population. The species that dominate the infestation are those best adapted to current management practices. As farmers adjust their management program to improve control of those species that are dominating the infestation, they typically create an opportunity for other species in the seed bank to escape and become part of the current problem. The longevity of most weed seeds in the soil allows them to persist in the field until their opportunity arrives. Due to the prolific seed production of most weed species, populations of weeds that have remained dormant in the seed bank for many years can become a major problem very quickly when provided the opportunity.

Herbicide resistance is another type of shift that can occur within a weed population. This shift involves a change within a weed species rather than among weed species. Just as the seed bank is comprised of numerous weed species, a population of a single species is comprised of many biotypes. Certain biotypes may contain a genetic trait that allows them to survive a herbicide toxic to other biotypes of the same species. Repeated use of a herbicide may result in the resistant biotype becoming a dominant component of the population. Numerous herbicide-resistant biotypes have been selected throughout Illinois and the Corn Belt after repeated use of herbicides.

Because most weed management systems are heavily reliant on herbicides, the relative susceptibility of different weeds to the herbicides being used has a major influence on weed shifts. However, other crop production practices influence weed shifts observed in the field. Understanding how management practices influence weed shifts can be as important in developing efficient weed management programs as studying herbicide effectiveness charts.

Second to herbicide use patterns, tillage is the management practice that has the greatest impact on weed populations. Tillage can affect weeds directly, as in the destruction of winter annual weeds during seedbed preparation, or the effect may be more subtle, as in the shift from large-seeded broadleaf weeds to small-seeded weeds in reduced tillage systems. Research has found that fields maintained under no-till production have more diverse weed seed banks than fields managed with intensive tillage. The more diverse seed bank does not necessarily mean that weed control will be more difficult in no-till; however, this diversity increases the potential for shifts and requires greater

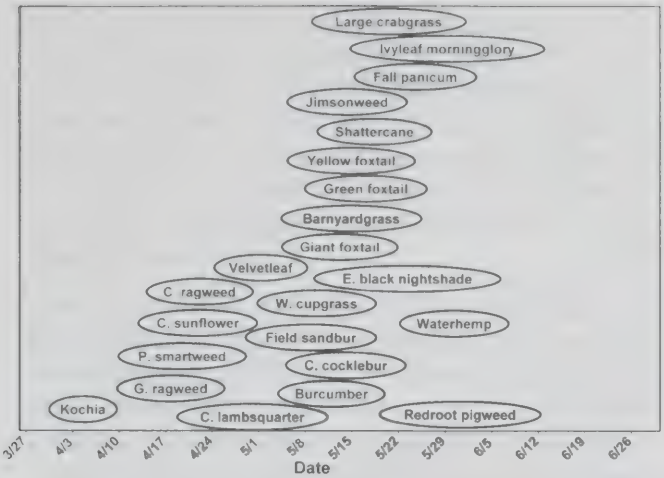

Figure 1 ■ Weed emergence profiles, 1997-98, Hartzler, Buhler, and Sandell, Iowa State University.

vigilance to adapt management practices to prevent rapid swings in weed populations.

Date of planting and other management practices also influence weed population dynamics. The influence of these practices on weed shifts often is mitigated by differences in growth and behavior of different weed species. No other event in the life cycle of weeds affects management as greatly as weed emergence. The timing and intensity of weed emergence affect effectiveness of burndown herbicides and preplant tillage, timing of postplant tillage and herbicide application, competitiveness of weeds that escape control, seed production by surviving plants, and eventually population shifts. Given the importance of weed emergence to all forms of weed management, it seems logical that we should give greater attention to understanding and predicting weed emergence as affected by environmental factors, weed species, and management practices.

Each weed species has a unique emergence profile. This profile is defined by the initial date of emergence, length of time over which emergence occurs, and distribution of emergence within this time period. Although emergence profiles vary from year to year depending upon environmental conditions, the emergence patterns of different species remain relatively consistent in relation to one another. For example, in central Iowa the initial emergence date for giant foxtail ranged from April 29 to May 15 between 1996 and 1998. In each of these years the initial emergence of velvetleaf occurred within 4 days of the initial emergence of giant foxtail.

The emergence profiles (initial emergence date and emergence patterns) of 23 annual species common to Iowa are summarized in Figure 1. The size of an oval provides information on both the length of emergence and distribution of emergence. Weed species with a small oval typically have most of their emergence close to their initial time of emergence, whereas species with a large oval have either an extended period of emergence or most of their emergence occurs further from their initial date of emergence. At any given time between early April and mid-June there are several weed species at their peak emergence, therefore requiring weed management programs that provide extended periods of control.

The emergence profile of a species significantly affects weed management programs. Giant ragweed has become a greater problem for many farmers in recent years. Part of this increase may be due to earlier planting dates currently practiced for corn and soybean. Giant ragweed is typically the first summer annual weed of corn and soybean fields to emerge in the spring. Because most giant ragweed seedlings emerge shortly after crop emergence initiates, the majority of the population would be killed by seedbed preparation with late April or early May planting dates. Earlier planting dates result in the majority of the giant ragweed population emerging after planting, therefore the ragweed must be managed by the herbicide program. In addition, the large seed size and adaptation of giant ragweed to cool temperatures allow the plant to rapidly reach sizes difficult for most herbicides to control consistently. Understanding differences in emergence patterns of the weeds present in a field can help in the design of effective management systems for specific weed problems.

Weed infestations are dynamic, and they require dynamic management programs. Although changes in weed infestations sometimes are caused by the introduction of new species, the most changes are due to weeds that already were present in the field but were maintained at noneconomic levels by previous management tactics. As weed management systems become increasingly reliant on herbicides, it is likely that weed shifts will occur more rapidly than previously encountered. Thus, monitoring fields and adjusting management programs quickly before the increasing weed population reaches troublesome levels will be more important than in the past.

Variable Rate Fertilization

Don Bullock and David S. Bullock

This article reports on a field experiment conducted by University of Illinois researchers in cooperation with producers in Illinois and Indiana during the 1996 through 1999 growing seasons. The investigators examined variable rate fertilization of phosphorus (P) and potassium (K) on actual production fields ranging from 40 to 120 acres. Multiple small plots of approximately 70 by 250 feet were established on each field. All fertilizer applications, planting, cultivation, and harvesting were performed with commercial equipment. All fertilizer applications were based on an initial soil test taken on a 1-acre grid at the start of the experiment. Yields were determined with global position system (GPS)-equipped yield monitors and calculated for each small plot with the geographic information system (GIS).

Two treatments were used. The first treatment was labeled whole field management (WFM) in which the entire field was farmed as one unit and a single fertilizer application rate was used. This treatment represents the rate that farmers would use in a conventional uniform broadcast application. Each of the WFM plots in a given field for a given year received exactly the same rate. The second treatment was labeled site-specific management (SSM) and each of these plots received a fertilizer application rate that was based upon the interpolated soil fertility map. Thus, the amount of fertilizer applied within each plot depended upon the fertility of the plot. There also was variability in the amount of fertilizer applied within each small plot. The technique used in the SSM plots is representative of the method used in commercial variable rate fertilization programs.

The fields used in this experiment are typical of well-managed fields in the central Midwest in that they are very fertile. Mean soil P (60–100 lb/acre) and K (300–450 lb/acre) values were near or exceeded the recognized yield-limiting values for corn and soybean production. Thus, for virtually all of these fields the appropriate recommendations for a uniform broadcast application of both P and K fertilizer application would be based only on crop need (i.e., maintenance) and would not include any attempt to further increase the soil level (i.e., buildup). This technique does not recognize that some areas of the field may have a soil fertility level substantially less than the field mean, which is particularly common for skewed data, such as we see in soil fertility research. For example, Figure 1 shows one of the fields used in this study. In this field the mean soil P level was approximately 72 lb/acre, but the white areas in the field had a soil P value less than 40 lb/acre. According to current recommendation standards, the white areas are predicted to respond to an increase in the soil P

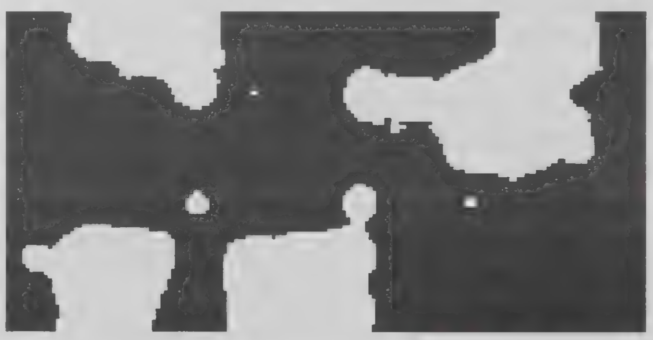

Figure 1

level. In this example, the SSM treatment resulted in more P fertilizer being applied than in the WFM treatments. This outcome of higher fertilization rates being used for SSM is typical of fertile fields. For fields that are less fertile the opposite can occur: SSM may call for less fertilizer. An expanded discussion of this point is presented in the oral presentation of this article.

Three years of field data indicate that the mean grain yield from the SSM-treated plots exceeded the mean grain yield from the WFM plots but only by approximately 2 bu/acre for corn and 1 bu/acre for soybean. This yield is substantially less than many have predicted should result from the use of variable rate fertilization. The cause of this lower-than-expected yield response is best understood when we recognize two details described in Bullock and Bullock (2000). First, the relationship between soil fertility and the economic optimum rate of application for these fertilizers is not a constant over a given field, even though all current recommendations implicitly make this assumption. Different areas of fields have different fertilizer requirements and many factors other than the soil fertility level determine the economically optimal fertilizer rate. Second, no farmer or agronomist currently knows the economically optimal fertilizer rate for each portion of a field. Such information is conceptually obtainable with agronomic experimentation. But in the past such experiments were not conducted because the information from the experiments would have been more expensive to derive than it was worth to farmers. But as we demonstrate in the oral presentation, the advent of precision agriculture production technology has increased the value of information, and so in the future, it may be worth it to producers and to society to conduct the agronomic experiments necessary to obtain the information.

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NASA Remote Sensing: Status of Weed Detection Research Efforts

Kenneth Copenhaver, Timothy Gress, Benjamin Varner, Christy Sprague, and Loyd Wax

Weed species were grown and spectral signatures were collected from an airborne hyperspectral system and a spectral radiometer for plots of six weed species within soybean and weed-free soybean. Separability analysis was performed between the scans for each weed type (weedy soybean and weed-free soybean) to determine whether spectral separability could be achieved. Separability analysis also was performed between broadleaf weed species and grasses. Classification algorithms, including spectral angle mapper and maximum likelihood, were then performed on the hyperspectral imagery to determine whether weed species within soybean could be classified separately from soybean and from each other. Results indicated that weed species mixed with soybean could be statistically separated from soybean, and broadleaf weed species could be separated from grasses in certain wavelengths. Separation by using classification algorithms on the hyperspectral imagery indicated that weeds (within soybean) can be separated from soybean by using automated techniques. However, separation between weed species requires manual manipulation of data.

Introduction

Competition from weeds is a major source of yield loss for soybean farmers. It is estimated that $6.1 billion was spent by American farmers on herbicides in 1997 (Economic Research Service 1998). The current methodology for weed control is to apply a herbicide uniformly throughout a field. However, research has indicated that weeds do not grow uniformly in a field; rather, they grow only in certain areas, often in patches with up to 94% of the field being weed free (Wiles et al. 1992, Mortensen et al. 1995). A majority of farmers currently use postemergence herbicide application techniques. Application occurs anywhere from 1 to 4 weeks after planting. This application method, depending on weather and weed species, usually gives weeds the opportunity to emerge and grow prior to herbicide application. Weeds also have a tendency to grow in clumps (Thornton et al. 1990). Thornton et al. (1990) showed that these clumps could be seen with a 35-mm camera from an airborne platform. Weed clumps should increase the biomass and near-infrared reflectance for areas of fields infested with weeds. Previous research with remotely sensed imagery has shown that imagery may be able to separate and identify weeds from bare soil by using the increase in reflectance in the near-infrared region during early season development, the time that a postemergence herbicide would be applied (Richardson et al. 1985).

Remotely sensed imagery also may be able to identify weeds based on the weed's spectral signature versus that of soybean or bare soil. Richardson et al. (1985) separated johnsongrass and pigweed from sorghum, cotton, and cantaloupe at the plot level by using an airborne video system with narrow-band filters in the blue, green, red, and near infrared. In Australia, Lamb and Weedon (2000) accurately identified the weed hairy panic 80% of the time in a fallow canola field by using a multispectral video camera with bands in the visible and near-infrared regions. Researchers at the University of Idaho are attempting to use hyperspectral sensors to detect and create spectral signatures for weeds. Preliminary results from this project look promising

and show greater success than previous work with multispectral camera systems http://plantain.ag.uidaho.edu/Mapping/hypercrop/dnrs.htm.

Project Goal

We intend to determine whether remotely sensed spectral information can be used to delineate weeds within soybean at the time of year a postemergence herbicide would be applied. We also attempt to separate spectrally different weed species. The soybean and weed research plots are located on the University of Illinois Crop Sciences Research and Education Center in Urbana, IL. The soil types are a Drummer silty clay loam and Flanagan silt loam.

A block of 10 weed species (giant foxtail, shattercane, barnyardgrass, giant ragweed, waterhemp, velvetleaf, Pennsylvania smartweed, redroot pigweed, cocklebur, and lambsquarters) was planted in a split-block design at the University of Illinois Crop Sciences Research and Education Center. Weeds were planted within rows of Roundup Ready soybean. Soybean without weeds represented one of the treatments. Three replications of each treatment were represented in a block. The weed species were planted after tilling and before planting the crop. Monocultures of weed seeds were broadcast for each species in the respective plots. Each plot measured 20 by 50 feet, ensuring a minimum 12-pixel coverage by using the 0.5-meter spatial resolution imagery provided by the RDACSH3 (Real Time Data Acquisition Camera System Hyper Spectral). A 2-meter buffer was placed between plots and tilled. University personnel cleared the weed plots of foreign weed species on a weekly basis until the flights occurred. Herbicides were not applied to the plots. Not all species were established successfully and only plots of five weed species were used for the study.

Imagery and Field Data Specifications

Radiometer scans were collected for each plot from 11:00 AM to 2:00 PM on four separate dates (June 1 to July 19) for each weed species based on growth stage (4 to 6 inches). Sixteen scans for each replication were collected. The radiometer (GER 1500) collects 512 spectral bands from 300 to 1100 nm. A 5-inch square spectralon panel was used after each replication to calibrate the sensor and allow for conversion from radiance to reflectance. The radiometer was mounted on a stable platform on an all terrain vehicle and used a fiber optic placed at an appropriate distance from the target to emulate a pixel from the imagery (0.5-meter swath). Scans were distributed evenly throughout the plot.

Table 1 ■ Timetable of weed and soybean growth stages. The imagery was collected for each plot at the growth stage (4 to 6 inches) at which the weeds would normally be sprayed with a postemergence herbicide.

June 1	Weeds planted (broadcast spreader from seed)
June 3	Soybean planted
June 30*	Shattercane and common waterhemp at 4 to 6 inches (soybean at V3)
July 7*	Velvetleaf, shattercane, waterhemp, and giant foxtail at 4 to 6 inches (soybean at V5)
July 13*	Common lambsquarters at 4 to 6-inch stage (soybean at V9)
July 19*	(final radiometer scans) All growing weed plots at postemergence stage

* Dates of image acquisition.

Sets of gray scale calibration tarps were laid near the plots. These tarps vary in their reflectance values (2, 4, 8, 16, 32, 48, 64, and 83%). Radiometer scans were taken for the placards as close to flight time as possible. The manufacturer guarantees the reflectance (to within ±1%) of the placards but radiometer scans ensured proper calibration for the date of the flight.

University of Illinois personnel scouted the plots closely during the period leading up to and during data collection to ensure that the weeds were growing properly. Areas devoid of weeds were mapped and undesirable weeds were removed from each plot. A global positioning system (±10-cm accuracy) was used to map the plot boundaries for geo-referencing the imagery and for mapping the locations of areas where weeds or soybean plants were failing to establish.

Imagery data were collected by using the Institute for Technology Development (ITD)/Spectral Vision's RDACSH3 hyperspectral sensor on the same days as the radiometer collections (Table 1). The RDACSH3 collected imagery at 0.5-meter spatial resolution (60 bands from 457 to 823 nm with 6-nm bandwidths).

Results

The primary goal of the project was to determine whether the spectral reflectance (visible and near-infrared wavelengths) for different weed species mixed with soybean was statistically different from a pure stand of soybean. An analysis of variance (ANOVA) was performed for the separate radiometer scans within each weed type planted between soybean rows and the soybean stand. An analysis of the results indicates differences in many areas of the spectrum covered by radiometer data. All five weed species mixed in soybean were separated from soybean in the green portion of the visible spectrum. Four of the weed species in soybean can be separated from soybean plants through much of the visible spectrum. Surprisingly, most weed species in soybean were difficult to separate from soybean plants in the near-infrared spectrum.

By using RDACSH3 imagery (June 30), an initial classification of the hyperspectral imagery was performed. By this date, only the shattercane and common waterhemp had reached maturity levels sufficient for detection. Mean radiometer signatures for each weed type were resampled to the spectral resolution of the RDACSH3 to create a spectral library. A supervised classification with the spectral angle mapper (SAM) algorithm was used for the classification in Environment for Visualizing Images software (ENVI 1997). The results show an ability to separate weeds from soybean but not one weed type from another. Additional analyses were performed by using a variety of classification and image enhancement techniques. A classification (first three bands) was created using a minimum noise fraction rotation. This classification contributed the best results and demonstrated the ability to separate shattercane from common waterhemp in soybean the majority of the time.

To determine whether broadleaf weed species in soybean could be separated from grass weed species an ANOVA was performed. Signatures collected from the radiometer for the broadleaf weed species were compared with the two grass weed species. The results indicated that in many areas of the spectrum the three broadleaf weed species were separable from the shattercane and the foxtail.

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Sensor-Based Precision Farming System

Lei Tian

This research integrated a real-time machine vision-sensing system and individual nozzle-controlling device with a commercial map-driven-ready herbicide sprayer. Thus, we created an intelligent sensing and spraying system. The machine vision system was specially designed to work under outdoor variable lighting conditions. We used multiple vision sensors to cover the target area. Instead of identifying individual plants in the field, weed infestation conditions in each control zone (management zone) were detected. To increase accuracy of herbicide applications, each spray nozzle was controlled separately. We evaluated the integrated system for its effectiveness and performance under varying commercial field conditions. By using the on-board differential global position system (GPS), geo-referenced chemical input maps (equivalent to weed maps) also were recorded in real-time. We compared the maps generated with this system with other sensing and referencing systems.

For major crop chemical applications, the current commercial sprayer controllers maintain a constant application rate by compensating for ground speed changes, a concept that was researched more than a decade ago (Gebhardt et al. 1974, Dickey-john 1987). To use geographical information system (GIS) or remote sensing information, research was initiated on map-driven variable rate sprayers (Rockwell and Ayers 1994). Because of the resolution of the weed map, the spatial resolution of these sprayer controllers was relatively low—the whole boom was controlled at one rate. Current postemergence sprayers have boom widths from 20 to 50 m. The timing of weed control was another issue. By the time weed maps were ready field conditions may have changed.

A system that could make use of the spatial weed distribution information in real-time and apply only the necessary amounts of herbicides to the weed-infested area would be much more efficient and minimize environmental impact. Therefore, a high-spatial-resolution, real-time weed infestation detection system seems to be the solution for site-specific weed management.

The concept design of the machine-vision-controlled sprayer is shown in Figure 1. The system includes a multiple-camera vision system, a ground speed sensor, and a nozzle controller. The application rate for each nozzle on the spraying boom is controlled separately based on local weed infestation conditions. Since 1996, three prototypes of the smart sprayer have been built and tested at the University of Illinois. We present information concerning the design and testing of the most recent prototype.

Prototype System Setup

The latest prototype was built on a Patriot XL sprayer (CASE-Tyler Industries Inc., Benson, MN). This self-propelled map-driven ready sprayer was equipped with an AIM control system with a differential GPS receiver with a 10-positions/s position updating rate. The sprayer traveled at 3.2–18 km/h (2–11 mph) during the experiments.

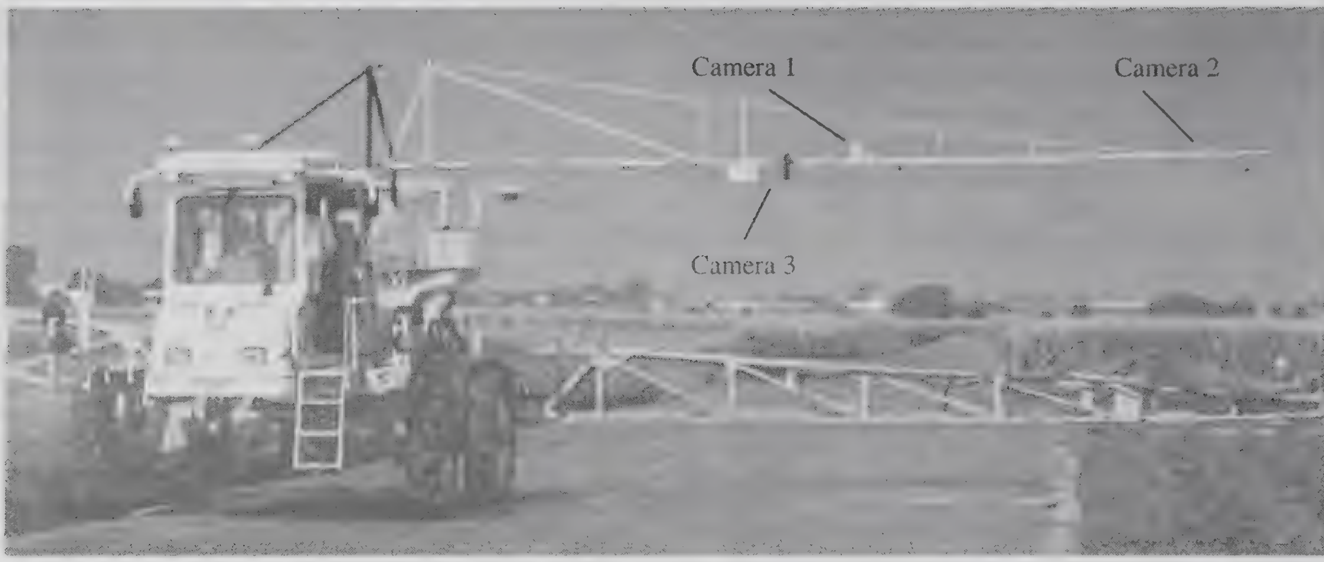

Figure 1 ■ Smart sprayer prototytpe system set up. Camera 1 is for vision system calibration, camera 2 and 3 are the cameras for real-time applications.

The nozzle controller was connected to the main computer by three links. First, a trigger line was used by the nozzle controller to command the main computer to take an image. This trigger line was connected directly to a trigger input line on the frame grabber. After initialization or processing of the prior image, the frame grabber was commanded to wait for a trigger. After the trigger was received, a time delay occurred because the frame grabber cannot "grab" the image until the start of the next image field. Immediately after the image was acquired, a strobe signal was sent back to the nozzle controller on the strobe line, the second link between the two computers. The strobe signal also was produced by a frame grabber digital output line. The third link was an RS-232 serial communication line that allowed the main computer to send individual nozzle commands after the completion of processing for a control zone row. The nozzle commands directed the nozzle controller to turn individual nozzles on or off.

Table 1 ■ Physical measurements for the prototype smart sprayer system.

Physical	Value
Image height/width	2.44/3.05 m
Vision system spatial resolution	0.005 by 0.005 m/pixel
Number of control zone rows/columns	4/6
Number of control zones per image	24
Distance between camera and spray boom	3.09 m
Control zone area	0.508 by 0.61 m^2
Sprayer boom width/nozzle spacing	6.1/0.508 m

Image Processing System

The image processing software was developed using Microsoft Visual C and the Windows application program interface (API) to create a graphical user interface that made possible a graphical display of the image processing results and ease in changing the software settings. Each image was first segmented with an environmentally adaptive segmentation algorithm (EASA, Tian et al. 1997). The EASA specifies the boundaries of a region in hue saturation intensity (HIS) color space that corresponded to the color of the objects in the outdoor scene through an interactive calibration window. Several variations of EASA program have been developed and tested with this machine vision system; the relatively reliable reduced dimension clustering (RDC)-EASA was selected for the final system (Steward and Tian 1999). To separate weeds from crop plants, additional information such as field location (different zones), crop row spacing, crop plant size (age), etc., was used in the image-processing algorithm. The crop rows were identified and the inter-row area was used for weed infestation condition measurement. We tested the hypothesis that weed patches are normally distributed across the inter-row and crop row area and the weed density is similar in a rela-

tively near neighborhood (within 1 m). So, the inter-row area weed density can be used to estimate the weed infestation condition in the crop row between plants. After all, we can only control and direct herbicide into unified grids (20 by 20 in.). To increase the image processing speed, several real-time weed density and weed leaf number extraction algorithms have been developed (Steward and Tian 1999).

Decision-Making Algorithm

The concept of economic chemical application threshold levels was the theoretical foundation for the decision on variable rate weed control. It is known that a crop can tolerate a certain pest level without a reduction in yield or quality (Barritt and Witt 1987). Therefore, costly (in terms of money and energy) practices need not be used in all cases when pests are present. One concern of using the threshold level concept is that new seed will be added to the soil each year because some weeds reach maturity. However, this weed seed should not be of major concern with many of the most common weed species because attempts to eradicate weed seed from the soil through weed control in a field have failed, as evidenced by the percentage of acres treated with herbicides (Barritt and Witt 1987). In addition, multiple-level thresholds could be realized with the continuous weed density information.

In our decision-making algorithm, a four-level application-rate scheme was selected. Because the vision system has a limitation of 0.005 by 0.005 m/pixel, a 10% label rate was selected as the base rate. This design eliminates the possibility of overlooking the infestation areas composed mainly of newly germinated weeds. Based on the sensed weed infestation conditions, three other levels of chemical dosage were assigned: 33, 66, and 100% of full application rate (from the label). The economic chemical application threshold was considered in the calculation of the application rate in the simulation test because information about weed numbers in each unit area and average weed size (age) could be used to make the decision to skip some low-weed-density control zones or to decide between multiple application rates for different weed infestation levels.

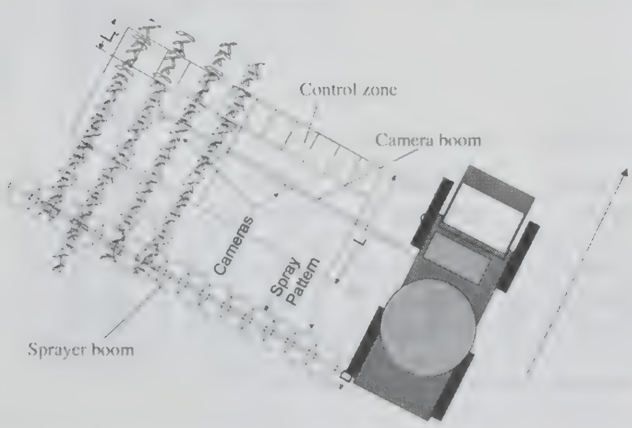

Figure 2 ■ System set up (top view).

Main System Control Program

The main system control program loop started with the program waiting to receive a trigger signal from the nozzle controller. When a trigger was received, an image field was acquired and the nozzle controller was strobed. The program then started processing the control zone rows, starting with the first row (closest to the spray boom, Figure 2). The image-processing algorithm calculates the weed density and weed size in each control zone. Based on image processing results, one of four specific dosages was assigned the corresponding control zone. Then the encoded nozzle command was set for the nozzle controller to adjust the corresponding nozzle to a certain duty cycle (Gopalaplai et al. 1999). When the entire control zone row was processed, the two-byte-long encoded nozzle control commands were sent for that control zone row. Processing continued, row by row, until all the rows were processed. Finally, the program returned to the beginning to wait for the trigger.

On the nozzle controller side, the nozzle control command is received and decoded first. When the distance sensor measures the right distance the nozzles are set to the corresponding application rate. The controller then counts the distance sensor pulses and waits for next right distance to arrive.

Field Experiments

Field experiments were conducted in large plots in 1999 and 2000 to evaluate the machine-vision controlled precision sprayer. Experiments were carried out in multiple fields, and under normal Illinois commercial farming conditions. Three fields

having contrasting soil types and weed species infestation were selected. The fields were located at the Agricultural Engineering Research Farm, Urbana, IL. The corn and soybean plots selected for this study contained crop plants that ranged in developmental age from 4 to 9 wk. Secondary tillage, just prior to planting, removed any early weed plants, so that weeds in the plots were about the same age as the crop plants. No preemergence herbicide was applied to the test plots. The precision sprayer traveled at 3.2–18 km/h (2–11 mph) during the experiments.

Special check plots were prepared for the system calibration. A 3.05 by 6-m area was weeded manually to create different levels of weed infestation and bare soil zones. The sprayer was driven very slowly and parked at different positions to check the response (spraying water on the weed infestation zone) and to adjust the camera and algorithm parameters to fine-tune the system. To assess system capacity, the sprayer was driven at different speeds to test the system response.

The delivery accuracy test was carried out on artificial targets. The distances from the start of the first full pattern on the plastic to the start or end of each of the subsequent spray patterns were measured. From these measurements, the lengths of the individual patterns could be determined. A randomized complete block experimental design was used with four replications of the three speed levels.

For the chemical saving experiment, both ground truth about weed infestation and remote sensing weed infestation area data were collected at the same time the sprayer field experiment was carried out. The amount of chemical consumption was recorded for both conventional and precision chemical applications. The conventional chemical comparison test was conducted with the same sprayer. Because the smart sprayer only used a portion of the boom on one side of the sprayer, the remaining part of the spray boom was set up to simulate conventional uniform rate application. The chemical input from the "smart spray" portion is recorded as a map (amount versus GPS location) and conventional spray chemical input is then equal to the total amount minus the smart sprayer amount. Weed distribution data from the weed map were plotted and analyzed with respect to these control zones (sampling grids). Weed-free or weed-infestation areas at different threshold levels were calculated. The result of this analysis demonstrated how different weed control methods affect the sprayer's performance.

Results and Discussion

The data collected belong in three categories: 1) system capacity test, 2) delivery accuracy test, and 3) chemical saving test. In the system capacity test, the maximum travel speed of the sprayer was measured. Table 4 shows the image processing time and the sprayer travel speed. With the current system design, the sprayer can travel up to 15 km/h. Errors caused by the introduction of distance delay by the video timing were negligible (Table 2).

The overall hit accuracy of the system was 91% (Table 3). Two types of errors were observed. In five cases, no spray pattern was observed anywhere in the vicinity of the target suggesting that the target was not correctly segmented as a target by the main computer. This outcome could be due to specula reflections of the plastic bag covering the target or to orientation of the target relative to the camera. In the remaining cases of missed targets, there was a spray pattern near the target, but the spray did not hit the target. The hit accuracy was 96% for the

Table 2 ■ Mean length measurements from field tests of the sprayer.

Speed level (km/h)	Pattern length test mode (m)	Distance fore (m)	Distance aft (m)	Distance left (m)	Distance right (m)	Pattern length (m)	Pattern width (m)
3.2–3.9	0.601a (0.070)	0.478a (0.241)	0.332a (0.209)	0.285a (0.133)	0.275a (0.154)	0.810a (0.270)	0.560a (0.190)
6.9–8.7	0.605a (0.037)	0.580a (0.206)	0.163b (0.212)	0.284a (0.153)	0.256a (0.167)	0.743a (0.235)	0.540a (0.199)
11–14	0.608a (0.031)	0.573a (0.215)	0.212b (0.231)	0.239a (0.134)	0.253a (0.149)	0.794a (0.295)	0.492a (0.197)

Letters indicate Duncan's multiple range test group at the 0.01 significance level. Values in parentheses are standard deviations.

Table 3 ■ Hit accuracy by speed level.

Speed level (km/h)	No. of targets not hit	No. of targets hit	Total no. of targets	Accuracy (%)
3.2–3.9	2	48	50	96
6.9–8.7	5	45	50	90
11–14	7	43	50	86
Total	14	136	150	91

lowest speed level. The hit accuracy decreased with increasing speed with 90% for the middle speed level and 86% for the highest speed level.

Based on the weed detection from the images in this randomly sampled data set, the weed distributions were best approximated by the negative binomial, which is coincident with some other weed distribution research (Cardina, et al. 1997). Figure 3 depicts the weed density frequency in the experimental field. In the experimental field, more than 80% of the control zones had less than 20% weed coverage.

This work showed that selective- and variable rate herbicide application methods had advantages over the uniform application method. The variable rate method had greater advantages when the weed density variation was high. In Table 4, proposed variable application rates are listed. Potential herbicide savings from comparing on/off and variable rate applications with uniform application are illustrated in Table 5, where the single (economical) threshold for on/off application was set at a weed density of 1% and the variable rate was set to four levels as in Table 4.

Figure 4 shows the chemical application map that also is the weed infestation area distribution map. Figure 5 shows an example of the correlation between weed maps and processed aerial image data. Figure 6 is the color near-infrared images of the treated field. The correlation between the aerial image and the weed map generated with the smart sprayer showed that this sensor-based real-time system also can be used for high-accuracy field variability mapping.

Summary

An automatic sprayer controlled by a real-time machine-vision system was developed and tested. The prototype system was designed with an optimization strategy of balancing the practical need for accuracy in field operations and the requirement for a real-time system. A low-cost micro-controller in conjunction with a computer running on a multitasking operating system were combined for selectively spraying objects that were sensed in real-time.

This type of hybrid system provides a low-cost alternative for the development of real-time machine vision applications without the development overhead of a customized real-time system. This approach could be used for a variety of precision farming applications where system events need to be synchronized with the location of stationary objects in acquired images relative to a moving sensing and control platform.

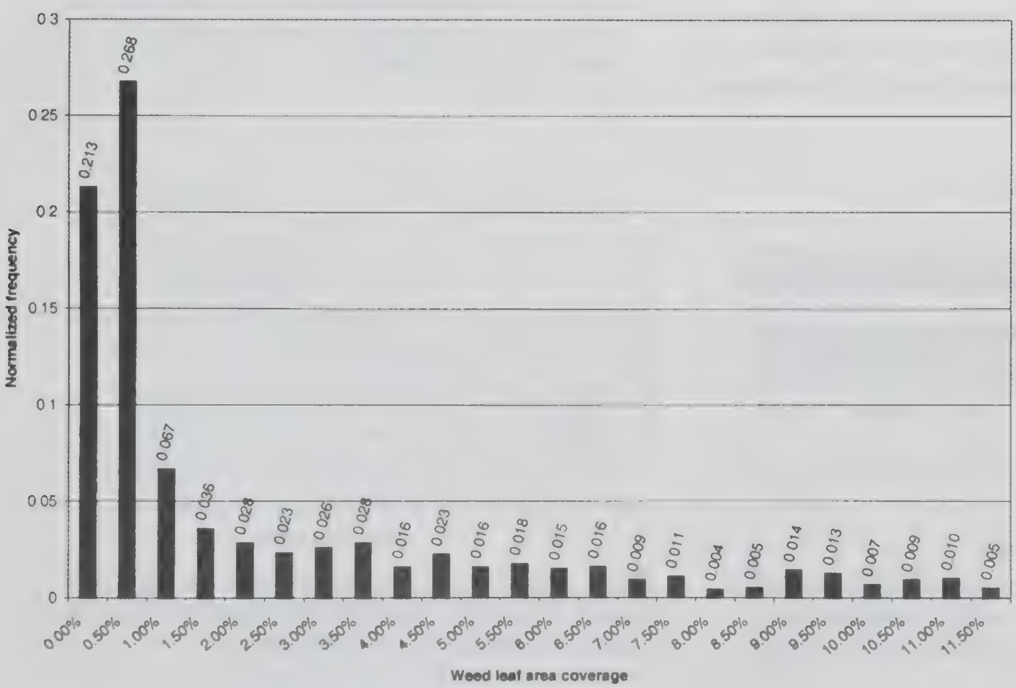

Figure 3 ■ Example of weed density distribution in the field.

Table 4 ■ Proposed variable application rates.

Weed density (%)	0–1	1–2	2–10	>10
Application rate (%)	10	33	66	100

Machine vision-guided cultivation and harvesting are two examples of such applications in addition to the application of herbicides.

General specifications for when system events should occur based on the physical configuration of the system were developed and could provide easy adaptation of these techniques to other applications and system configurations. The test results demonstrated that the system operated with a 91% overall accuracy.

The precision chemical application embraces the concept of creating a balanced crop–weed ecosystem in the field with the lowest cost and minimal environmental impact. With the availability of such a precision sprayer, new questions are generated that require interdisciplinary cooperation to discover answers. Further research and experimentation are needed to determine the optimal chemical input amount for different crop and weed coverage, control zone size, and timing combinations. The knowledge of agricultural engineers, agricultural economists, weed scientists, and agrochemical experts must be combined to develop the high-performance expert system required for a precision sprayer. When fully developed and available, the precision sprayer will be a great benefit in increasing agricultural profitability and to society by reducing environmental damage.

Table 5 ■ Herbicide savings over the uniform application method.

	Very high weed density plot (STD = 0.18)	Normal weed density plot (STD = 0.05)
Single threshold method	6%	52%
Variable rate method	18%	71%
Ratio of VR/ST	3	1.36

STD, standard deviation of weed density; VR/ST, variable rate/single threshold.

Acknowledgments

This research has been supported by the Illinois Council of Food and Agricultural Research (C-FAR), Project Number 97I-124-3; and the Research Board of the University of Illinois.

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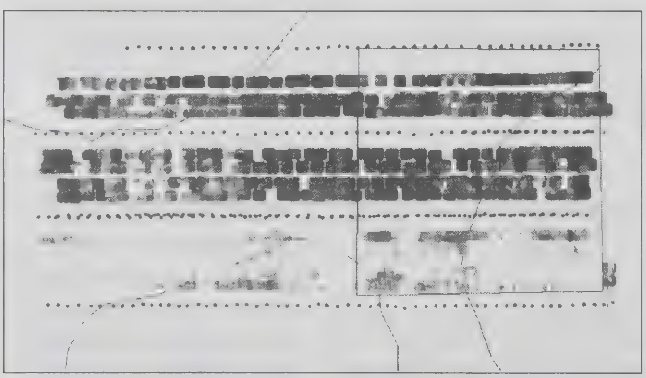

Figure 4 ■ High resolution weed map (400 mm/pixel) generated with ground truth machine (dark points represent high weed density) overlaid on top of soil type map.

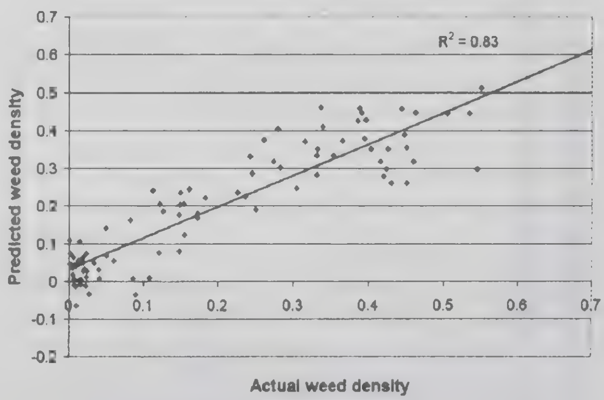

Figure 5 ■ Weed density predicted from RS image (Figure 4) using Artificial Neural Network vs. actual ground truth weed density (Figure 1).

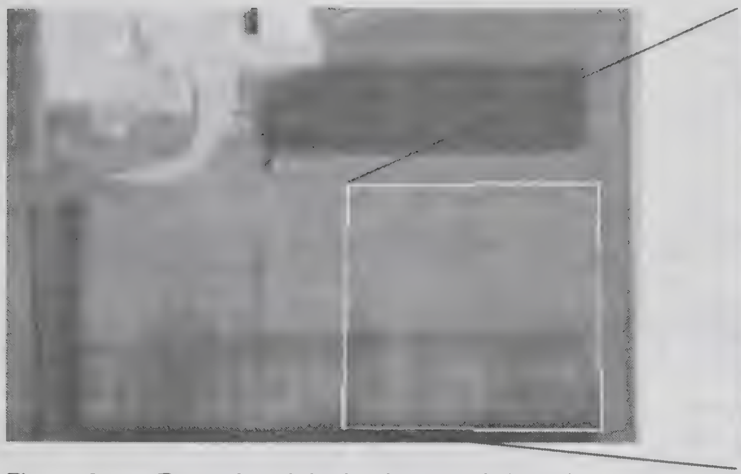

Figure 6a ■ Example original color near-infrared image of a test plot at a resolution of 1meter per pixel (Soybean field, 7-23-1998).

Figure 6b ■ Image taken on the same day with higher spatial resolution aerial imaging system (300 mm/pixel).

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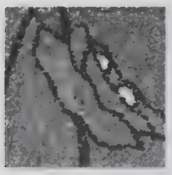

Using Precision Farming Technology in Identity Preserved Systems

Todd Peterson

You need only to pick up a newspaper to learn that some parts of our grain production and marketing system are struggling with the concept of tracking and segregating grain. Millions of dollars are being spent developing specific test kits, sampling and testing grain headed for different markets, and purchasing grain that may be "contaminated" with grain that does not meet the specifications for a certain market. At the same time the public is becoming aware of the costs of not segregating grain, some growers are recognizing significant value in segregating their grain and maintaining adequate records to prove it. This article discusses some ideas to help producers use precision farming technology to segregate grain, maintain spatial records, and improve efficiency and add value to the grain they are growing.

A Picture Is Worth a Thousand Words: Using Maps to Enhance Communication

Farming is a complicated business. Many individual farm operations are growing both in size and complexity. Low operating margins allow little room for "mistakes" in the farming process. Effective communication and clear information exchange about the process of growing a crop is key to a farm's success. In my experience, growers and those who work with growers tend to be visual learners. Spatial data displayed in the form of a map can enhance communication between all parties involved in crop production: a grower and his or her input suppliers, a decision-maker and other employees involved in the operation, a tenant and landlord, a grower and agricultural lender or farm management firm, a grower and a custom applicator, and a grower and the buyer or grain end user.

Maps can be used to improve communication at different times during the growing season. In Pioneer's business of supplying seed to growers, decision-makers greatly appreciate the value of a field map during preseason planning discussions. New technologies available include value-enhanced genetics targeted to specific end uses of grain, as well as seed products with insect resistance or herbicide tolerance. These products offer additional value opportunities for farmers, but usually require a higher level of management. For example, growers using corn hybrids containing *Bacillus thuringiensis* (Bt) genes for insect resistance must follow a specific resistance management plan that includes a refuge area planted to non-Bt hybrids, to reduce the chance of insects developing resistance to the Bt protein.

Maps are useful tools during the growing season as well. Maps can aid producers in planting the proper hybrid or variety in specific locations, and help reduce errors in the application of fertilizers or crop protection products. Nearly everyone attending this conference is probably aware of a mistaken herbicide application to a crop that does not contain the appropriate herbicide resistance genes, and most of these mistakes can be prevented with proper communication enhanced by the use of a map. Farm-scale maps show each field, road, grain bin, etc., and can improve operations at harvest. Many of Pioneer's cooperators have used farm maps to communicate and coordinate activities with part-

time employees assisting during harvest because these employees may not be familiar with all aspects of the farm and fields.

Use Precision Farming Tools Year-Round

North American grain farmers are rapidly acquiring yield monitors, global positioning system (GPS) receivers, and mapping systems to record and map yields at each point in their fields. Yield maps are considered the most effective if growers have thoroughly documented all relevant field information, including site attributes and field operations. Yet it is amazing how many growers only use their yield monitors and GPS receivers during the harvest season, leaving these expensive and useful tools to gather dust 11 months of the year. A major effort of the precision farming group at Pioneer is to help growers make use of these tools to document planting and other field operations throughout the year.

The easiest way to collect site information during field operations is to simply move the yield monitor and GPS receiver from the combine to the cab of the tractor used for the field operation, e.g., planting. Ag Leader Technology of Ames, IA (www.Agleader.com), has made this easy and relatively inexpensive by marketing the needed brackets, cable hookups, run/stop switches, and minor software upgrades. Most farmers using their yield monitor in the planter tractor simply name their "loads" as the hybrid or variety being planted, or the management practice being varied.

Owners of other brands of yield-monitoring systems can often use their monitor or some portion of their system to accomplish the same goals. Owners of Case AFS and John Deere GreenStar yield monitors can use their system components at planting time but the practice may not be fully supported by all dealers at this time. Independent vendors, consultants, and other input suppliers often can help clients interested in using their existing hardware to collect site information and document field operations.

Another option is to simply use a GPS receiver and a laptop or portable PC for storing the data. Software is available for inexpensive hand-held Windows CE machines, and a variety of programs are available that can run on older laptop computers. Site data also can be collected by using a communication package that allows logging the GPS data and saving these data as an ASCII file.

Benefits of an "As-Planted" Map

Using GPS on the planter tractor to create an "as-planted" map during planting has proven very useful to growers. It helps document the value of the seed supplier's recommendations for each specific field. The number of hybrids and varieties available to a producer increases every year, and it becomes more important to get the right genetics placed in the proper field for optimum production. Because GPS receivers collect and record position (latitude and longitude) as well as time in GPS seconds, the as-planted map can be used to document exactly where and when each field is planted. This approach has been very useful to growers when planting is interrupted by rain, or when they need to return to the field to "fill-in" wet spots that could not be planted at the same time as the rest of the field. If the planter mapping system is equipped with an implement switch that only logs data when the planter is in the operating position, the as-planted map also provides a very accurate record of the acres planted in each field and each hybrid or variety.

Typically, when Pioneer's precision farming group assists a grower beginning to map his or her planting operations, the grower begins to recognize the value of logging and mapping **all** field operations. As soon as planting is finished, the mapping components are usually shifted to the sprayer tractor to log and map all spraying operations. A side benefit of this process is that the grower is using the yield mapping components throughout the growing season, he or she does not need to spend additional time getting retrained on the use of the yield monitor at harvest time … the operation of the monitor has been practiced throughout the year.

Benefits of Spatial Data When Selling the Crop

By now it should be obvious how the use of spatial data on planting, fertilizing, spraying, and harvesting could contribute to a set of records for quality

assurance documentation to the buyer of your grain. Many end users are implementing programs to segment their markets and help them choose preferred grain suppliers they intend to work with over the long term. Growers who choose to use their precision farming tools to document their field operations will likely be in a better position to capture these opportunities. We will soon have the ability to measure grain quality on the go at harvest time. The opportunity to sell a load of grain for a premium over the normal market price will be enhanced if the grower can supply a complete set of quality-assurance records along with that grain.

Nitrogen Management: What We Know Now—Will It Make a Difference?

Robert G. Hoeft

Nitrogen management has been of importance to society for many years. Concerns about nitrogen management are increasing because of low commodity prices associated with the large world grain supply, increased energy prices, and the impact of excess nitrogen on the environment.

Throughout most of the last decade, world grain production has been more than adequate to meet demand. As a result, commodity prices have remained low relative to production cost. The recent increase in energy prices will further narrow the margin between cost of production and value of the commodity in the marketplace. Because fertilizer, particularly nitrogen, is a significant portion of the cost of crop production, nitrogen management needs to be at the highest level possible for U.S. farmers to compete in the international grain market.

Tight energy supplies inevitably will result in significant price increases for fertilizers; particularly nitrogen, because significant amounts of natural gas are consumed in manufacturing each ton of nitrogen fertilizer. Although the amount of natural gas used in the production of fertilizers is small compared with the total amount used in the United States, any improvement in management that reduces nitrogen use will result in more natural gas for other segments of society.

Agriculture has been identified as a contributor of nitrogen to surface and groundwater supplies. Although there is evidence that nitrogen contamination from the land preceded modern farming (Krug and Winstanley 2000), improper nitrogen management may worsen the problem. Nitrogen in water supplies is not only a public health concern but also contributes to eutrophication, or the enhancement of algae and other aquatic plants. Enhancement of the hypoxic zone in the Gulf of Mexico has been attributed at least in part to nitrogen contamination from the Mississippi River Basin. Even though the relationship between fertilizer consumption in Illinois and the size of the hypoxic area is weak (Table 1), nitrogen may still be a causative factor, or other factors may be involved, such as rate of water flow in the Mississippi River; concentration of phosphorus, silica, and organic carbon in the river; and timing and intensity of storms in the Gulf of Mexico.

Can the Efficiency of Nitrogen Use be Improved?

Since nitrogen fertilizers were first introduced into the marketplace, scientists have worked to identify what are now called "nitrogen best management practices" that would optimize the efficiency of crop production. These practices include 1) using the correct rate for the crop to be grown; 2) applying the fertilizer at the right time; 3) taking credit for home-grown nitrogen; 4) ensuring accurate application rates; 5) using nitrification inhibitors; and 6) using good crop management practices. Fortunately, these practices also minimize the potential for environmental contamination.

Table 1 ■ Illinois nitrogen fertilizer sales and size of the hypoxia area in the Gulf of Mexico.

Year	Nitrogen fertilizer sales ton of N	Size of hypoxia area Square miles[1]
1985	1,014,519	3,777
1986	945,370	3,644
1987	840,968	2,584
1988	938,457	15
1989	952,242	No data
1990	897,135	3,578
1991	1,006,302	4,606
1992	951,453	4,175
1993	865,618	6,794
1994	1,026,620	6,414
1995	884,438	7,032
1996	980,783	6,924
1997	989,888	6,120
1998	932,118	4,822
1999	973,029	7,728
2000		1,700

[1] Data source: Hypoxia studies of N.N. Rabalais, R.E. Turner, and W.J. Wiseman, Jr.

Best Management Practices

1. Use the proper rate

Year-to-year variation in climate has a tremendous influence on the amount of nitrogen consumed by the crop (yield potential) and the amount of nitrogen produced by the soil system. Because this climatic variability cannot be predicted, a precise estimate of the amount of nitrogen needed each year is not possible. For example, in one study site the optimum rate varied from 53 to 240 lb N/acre over a 16-year period with an average need of 141 lb N/acre. The average nitrogen need in this study was slightly less than the current University of Illinois recommendation (1.0 lb N/bushel compared with the recommended level of 1.2 lb N/bushel). By using the University of Illinois recommendation, the amount of nitrogen needed at this site would have overestimated nitrogen need in 13 of the 16 years and underestimated it in 3 of the 16 years.

Research has demonstrated that nitrogen rates in excess of those needed for optimum crop production increase the amount of nitrogen lost through tile lines. Data collected on farms in Champaign County indicate that when rates were kept within 15 lb N/acre of the recommended rate, the weighted average concentration was 10 mg NO_3^-–N/liter. When rates were 30 lb N/acre or more above the recommended rate, the weighted average concentration was 14 mg of NO_3^-–N/liter. The difference in nitrate loss on a per-acre basis between these two groups of farms was even greater—15 lb N/acre for the fields receiving within 15 lb N/acre of recommendation compared with 46 lb N/acre lost from fields that had received more than 30 lb N/acre above the recommended rate.

Many scientists have devoted their careers to developing a nitrogen soil test. Unfortunately, most of them have failed to develop one that works in the majority of Illinois fields. Because of the development of a new soil test by Richard Mulvaney and Sadeed Kahn, University of Illinois, this situation is about to change. Whether agronomists will be able to use the results of this test to set the nitrogen rate for each field is yet to be determined, but the test definitely will be able to identify fields that will produce an optimum yield without additional nitrogen fertilizer. Fields with amino sugar-N values greater than 250 mg/kg will not need additional nitrogen (Table 2). Use of the test to identify fields that will not respond to nitrogen fertilizer will have a great influence on the potential for nitrate contamination of water supplies.

2. Apply nitrogen at the right time

Do not apply nitrogen in the fall for corn on any soil type in southern Illinois, or on sands or poorly drained soils in central or northern Illinois. Fall application must be limited to soils that have a relatively low nitrogen loss potential, and application should be delayed until soil temperature is below 50°F if a nitrification inhibitor is not used and until 60°F if an inhibitor is used. Irrespective of temperature, nitrogen should not be applied in the fall until after the second week of October in northern Illinois or the third week of October in central Illinois.

Even when these best management practices are followed, there will likely be somewhat more nitrogen lost through tile lines from a fall application than from a spring application. A 3-year study in Champaign County has shown that the flow-weighted concentration of nitrogen in tile lines is greater with a fall (17.9 ppm) than spring (11.5 ppm) application of nitrogen. Even though the concentration throughout the year is greater, there was little difference in the content of lost nitrogen on a per-acre basis: 50 lb N/acre (fall-applied nitrogen) and 45 lb N/acre (spring-applied nitrogen).

3. Take credit for homegrown nitrogen

Legumes, soybean, alfalfa, and clover all give apparent nitrogen credit for the following grass crop. Nitrogen rates should be reduced by 40 lb/acre for corn after soybean and by 100 lb/acre for corn after a good stand of alfalfa or clover. These estimates are conservative estimates of the nitrogen contribution from legumes. If manure or sludge have been applied, be sure to have an accurate measure (know the content of the manure and the rate of manure applied) of the amount of nitrogen applied and then reduce the nitrogen rate accordingly.

Table 2 ■ Relationship between amino sugar-N and crop yield response to fertilizer N.

Previous Crop	Manure N lb N/acre	Amino sugar-N (ppm)	Yield response to fertilizer (%)
Nonresponsive sites			
None	>1000	411.8	0.09
Soybean	500	411.0	–0.09
Alfalfa	0	266.8	–0.15
Soybean	190	501.9	0.10
None	2510	510.6	3.3
Corn	85	260.0	0.06
Soybean	210	350.3	0.18
Corn	0	323.0	–0.06
Soybean	100	314.0	0
Corn	0	360.2	–0.28
Soybean	0	303.4	0.27
Responsive sites			
Soybean	0	116.1	45.5
Corn	0	192.5	17.0
Corn	0	129.1	76.2
Wheat-double cropped milo	0	138.7	81.2
Soybean	0	194.5	67.9
Soybean	0	124.4	76.2
Wheat-double cropped soybean	0	45.8	121.5

4. Take credit for incidental nitrogen

Nitrogen is often applied as a part of another operation. Nitrogen applied as an ammoniated phosphate, starter, or carrier for pesticides should be credited. For example, an application of 200 lb/acre diammonium phosphate contains 36 lb N/acre and this amount should be credited as a part of the total nitrogen program. Similarly, the 30 lb N/acre applied with 10 gallons of 28% UAN as a carrier for herbicides should be credited as a part of the total nitrogen program.

5. Use nitrification inhibitors to reduce the rate of conversion of ammonium to nitrate

Minnesota results show that there will be less nitrate in tile line drainage if a nitrification inhibitor is used with fall-applied nitrogen. In fact, the amount of nitrogen lost in tile lines was no greater from a fall nitrogen application with an inhibitor than the amount lost from tile lines with a spring application of nitrogen without an inhibitor.

6. Use good crop management practices

Avoid compaction, plant early, use high-yielding varieties planted at a high population, maintain optimal soil test levels for pH, phosphorus, and potassium, and control weeds and insects.

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Approaches to Protecting Water Quality: Voluntary or Regulatory?

George F. Czapar

Introduction

Everyone seems to agree that protecting water quality is a top priority, but there is considerable debate on the best approach to address the problem. Although water quality has improved significantly over the past 25 years, agriculture continues to be identified as a remaining source of water quality impairment. Strategies for protecting water quality range from strictly voluntary approaches to increased regulations.

The Illinois Environmental Protection Agency (IEPA) maintains an extensive surface water-monitoring program that includes more than 15,000 miles of rivers and streams (IEPA 2000a). Figure 1 shows that 35% of the rivers and streams were rated as good in 1972. In the latest assessment of stream water quality conditions (Figure 2), the percentage of rivers and streams rated as good increased to 63%. Although municipal and industrial point sources of contamination have been reduced, agriculture is listed as a source of impairment for more than 75% of the rivers and streams.

The amount of water quality information on the Internet continues to increase. Resource materials, detailed maps, and water quality data are readily available (NCSU 1999, National Agricultural Library 2000, USGS 2000). The EPA has a site called "Surf Your Watershed" (U.S. EPA 2000c). It provides detailed water quality information for local areas and links to other sources of data. Users can search for local information by watershed, hydrologic unit, stream name, town, or zip code. Watershed characteristics, maps, environmental profiles, and water and land use data are available.

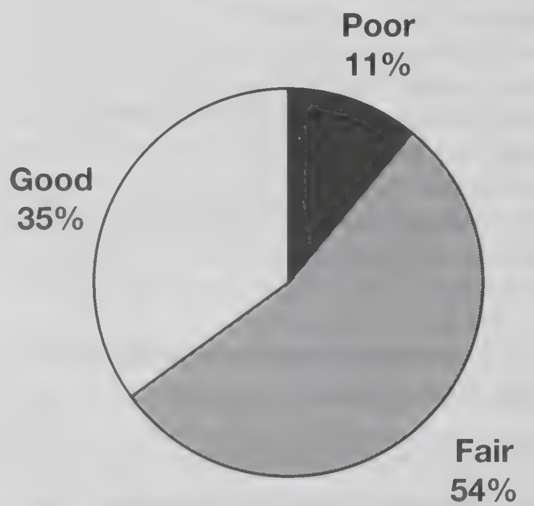

Figure 1 ■ Stream water quality conditions, 1972 (source: Illinois EPA).

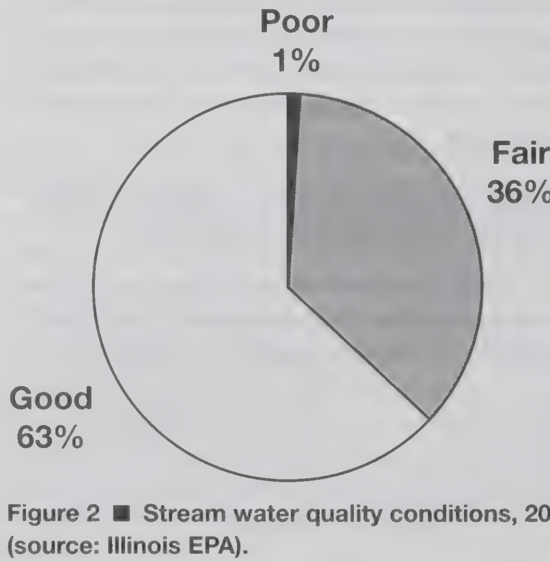

Figure 2 ■ Stream water quality conditions, 2000 (source: Illinois EPA).

Similarly, the Illinois Watershed Management Clearinghouse (UI 2000) Web site is designed to help individuals and groups address local water quality issues. This site contains information on managing and collecting watershed data, watershed management models, and summaries of ongoing watershed efforts. Also included are several interactive mapping systems and links to other data sources.

Finally, all public water supplies are required to provide their customers with an annual drinking water quality report. These "consumer confidence" reports are intended to provide consumers with information about the quality of their drinking water and increase participation in water protection efforts (IEPA 2000b, U.S. EPA 2000a).

Approaches

When Illinois fertilizer and chemical dealers were asked to identify the most successful approach for protecting water quality, filter strips and other best management practices (BMPs) were ranked as the best options (Czapar et al. 2000). Grower educational programs and application method and timing also were identified as likely to succeed. In contrast, product label changes and government regulations were deemed less likely to succeed in protecting water quality.

Ribaudo et al. (1999) evaluated several different approaches for reducing nonpoint source pollution. They compared economic incentives, standards, education, liability, and research as policy tools. They reported that a combination of these tools is often necessary due to the variety of water quality problems, differences in agriculture, and hydrology. They also suggest that agricultural policy tools should be tailored to the individual watershed whenever possible by state and local authorities.

Voluntary efforts, local watershed groups, and incentive programs have been used to address local water quality issues. The Illinois Council on Best Management Practices (C-BMP) is a coalition of agribusiness, agricultural organizations, and University of Illinois Extension. Its mission is to assist and encourage adoption of BMPs to protect and improve water quality in Illinois. The council provides information and support to local watershed groups and cooperates with water quality initiatives.

A number of federal, state, and local programs have been established that provide incentives for water protection efforts. For example, the Conservation Reserve Enhancement Program (CREP) is a joint, state–federal program intended to reduce sedimentation and runoff (FSA 1998). In return for planting riparian buffers, growers can receive rental payments and other incentives. Interest in this program continues to increase.

Regulatory approaches that are receiving the most attention include total maximum daily loads (TMDLs) and the effect of nutrient loading on oxygen depletion in the Gulf of Mexico. A TMDL is the maximum amount of a pollutant that a waterbody can receive and still meet water quality standards (U.S. EPA 2000d). Because individual states are responsible for these standards, it creates a challenge to identify impaired waters and develop plans to address the problems.

The zone of hypoxia in the Gulf of Mexico has received considerable attention. Hypoxia occurs when dissolved oxygen concentrations get too low to sustain most animal life, generally below 2 parts per million. The National Science and Technology Council published their integrated assessment of the hypoxia situation (CENR 2000) and all six assessment reports are available online (NOAA 2000). The current discussion centers on the contribution of Midwest agriculture to this problem, and the best way to reduce nutrient loading into rivers and streams.

The U.S. EPA (2000b) recently developed a technical guidance and reference document for the implementation of nonpoint source pollution management programs. This publication describes best available and economically achievable means of reducing nonpoint source pollution of surface and groundwater from agriculture. It identifies management practices for nutrients, pesticides, erosion and sediment, animal feeding operations, grazing, and irrigation water. This draft document is open for public comment until January 16, 2001.

Summary

In most cases, a combination of approaches will be required to achieve water quality goals, and the suggested practices may vary depending on soils, topography, and individual farm operation. Addressing water quality problems at the watershed level is more likely to be successful than treating every acre the same way. If voluntary approaches

and incentive-based programs fail to adequately protect water supplies, additional regulations will probably be imposed.

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Gulf of Mexico Hypoxia and Midwest Agriculture

Dennis McKenna

The Harmful Algal Bloom and Hypoxia Research and Control Act of 1998 (P.L. 105-383) requires that the President, in conjunction with the chief executive officers of the states, submit a plan to reduce, mitigate, and control hypoxia in the northern Gulf of Mexico. The law also requires that the plan include the social and economic costs and benefits of the measures for reducing hypoxia. As a first step in addressing the hypoxia issue, six teams of federal and university researchers analyzed existing data and applied existing models to characterize hypoxia in the northern Gulf of Mexico, evaluate the ecological and economic consequences of hypoxia, identify sources of nutrients, identify and evaluate methods to reduce nutrient loads, and evaluate the social and economic costs and benefits of those methods. These reports were synthesized in an Integrated Assessment that was published in May 2000 (CENR 2000).

The hypoxic zone is an area in the northern Gulf of Mexico where dissolved oxygen concentrations in the shallow ocean water are less than 2 mg/l, the level necessary to sustain most aquatic life. In response to the low oxygen levels, mobile organisms, such as fish and shrimp, leave the hypoxic zone; the others die at varying rates. Although these responses have been observed in the Gulf, an economic analysis based on past data did not detect a direct relationship between hypoxia and Gulf fisheries.

The size of the hypoxic zone varies considerably from year to year depending on the timing and extent of water-column stratification during the spring and summer, weather conditions, temperature, and the amount of precipitation in the Mississippi River drainage basin. In 1999, the hypoxic zone was approximately 20,000 sq. km, the greatest extent since measurements began in 1985. In the summer of 2000, it was approximately 4,400 sq. km, the smallest area since the drought year 1988.

The occurrence of hypoxic conditions depends on stratification of the water column—warm, less dense freshwater above cold, more dense saltwater—and consumption of oxygen during the decomposition of organic materials. The organic matter in the lower part of the water column is a result of algal growth and death in the surface waters. The growth of the algae is controlled by the presence of nutrients. In saltwater systems such as the Gulf, nitrogen is the nutrient that limits algal growth. In freshwater systems, phosphorus is the nutrient that most often controls algal growth.

A significant increase in nitrogen loads to the Gulf, principally in the form of nitrate, has occurred since approximately 1970. Nitrate loads tripled from approximately 0.33 million metric tons/year during 1955–1970 to 0.95 million metric tons/year during 1980–1996 (CENR 2000). During the 1980–1996 period, total nitrogen flux was approximately 1.6 million metric tons/year. Agricultural nonpoint sources have been identified as the source of approximately 74% of the nitrate and 65% of the total nitrogen reaching the Gulf. The principal areas identified as contributing nitrate are Illinois, Iowa, Indiana, Ohio, and southern Minnesota (CENR 2000).

Long-Term Goals

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force, consisting of representatives of eight federal agencies and nine of the 31 states and two tribal governments within the basin, met on seven occasions to discuss the issue and develop the action plan required by P.L. 105-383. In July 2000, the United States Environmental Protection Agency (U.S. EPA) published a draft action plan for public comment. Perhaps, the most controversial aspect of that plan was a goal to reduce nitrogen loadings to the Gulf of Mexico by 20 to 40% within the next 10 years. Approximately 100 individuals, agencies, and nongovernmental agencies commented on the proposed plan. In general, public comments were as anticipated: environmental organizations supported the plan, adoption of a quantitative goal, and a regulatory approach for point sources; agricultural agencies and organizations criticized many aspects of the plan, and opposed a quantitative goal and a regulatory approach. In October, the Task Force met in Baton Rouge, LA, to consider the public comments and finalize the action plan. After much discussion the Task Force adopted a goal to reduce the 5-year running average area of Gulf of Mexico hypoxia to less than 5,000 sq. km by the year 2015. The Task Force did not adopt a quantitative goal for reduction of nitrogen loadings to the Gulf because the farm-state representatives had significant uncertainties about 1) the effects of a specific level of nitrogen reduction on the size of the hypoxic zone, 2) the economic and social costs and benefits of proposed solutions, and 3) the impacts on agriculture and cities within the basin. However, the Task Force agreed that the best current science says that to make significant progress toward that goal, average nitrogen loads to the Gulf should be reduced by 30% from the 1980–1996 average.

Effects on Midwest Agriculture

To achieve a significant reduction in nitrogen loading to the Gulf, the U.S. EPA proposed in October 2000 that farming practices be changed to reduce nitrogen losses and that 5 million acres of wetlands and 27 million acres of riparian areas within the Mississippi River basin be restored to remove nitrogen from surface water and groundwater. In the Midwest, grain producers may be able to reduce edge-of-field nitrogen losses by 10 to 15% with best management practices, such as adjusting rates and timing and proper crediting of legumes, without affecting yields. Other producers, who have already fine-tuned their nitrogen inputs, will not have that management option. The restoration of 32 million acres of wetlands and riparian areas would result in the conversion of only 4.4% of the entire Mississippi River basin. However, creating millions of acres of wetlands or riparian areas could have tremendous impacts on Midwest agriculture.

The economic analysis conducted as part of the analysis of the hypoxia issue did not address economic impacts within specific states or watersheds. However, the report (Doering et al. 1999) concludes that "Severe restrictions on nitrogen loss from agriculture mean that production ceases on acres in the Mississippi River basin that are especially vulnerable to nitrogen loss" (e.g., the Illinois River basin). Neither the economic analysis nor the Integrated Assessment addresses the comparative costs and benefits to the industries potentially affected by the Gulf hypoxia issue. The Integrated Assessment (CENR 2000) states that the fisheries of the Gulf generate $2.8 billion annually. In 1997 Illinois alone exported more than $3.7 billion in commodities; total cash receipts were more than $9 billion. Although the CENR reports found no economic impacts on the Gulf fisheries as a result of hypoxia, the proposed solutions could have severe impacts on the economy of states such as Illinois.

Moreover, the validity of the economic analysis is questionable because an aggregate analysis of effects within the entire nation or the entire Mississippi River basin does not reveal the severe economic disruptions to agriculture in states such as Illinois, Iowa, Indiana, Ohio, and Minnesota. Other reports have identified these states as the largest sources of nitrogen and likely the most effective locations for management practices such as wetlands. In most parts of Illinois where restoration of wetlands or riparian areas should be targeted to reduce nitrogen, cropland sells for more than $4,000/acre and enrollment of these acres in a wetland or riparian area program would be very expensive. In addition, these soils are the most productive in the state and the lost yield would be proportionately greater. The lost production would affect not only agricultural producers and suppliers but also the entire Illinois economy.

Mitsch et al. (1999) provided estimates on the most effective distribution of wetlands and riparian areas

Table 1 ■ Effects in Illinois of proposals to restore 32 million acres of wetlands and riparian areas.

Basinwide reduction proposals	Acres converted in Illinois	% of cropland acres	Bushels of corn/ beans @ 180-bu corn/50-bu beans	Production value @ $2.00 corn/ $5.00 beans ($)	Total production value ($)
5,000,000 acres of wetlands	850,000	3.6	76,500,000/ 21,250,000	153,000,000/ 106,250,000	259,250,000
27,000,000 acres of riparian areas	4,590,000	19.5	413,100,000/ 114,750,000	826,200,000/ 573,750,000	1,399,950,000
Total	5,440,000	23.1	264,960,000/ 73,600,000	979,200,000/ 680,000,000	1,659,200,000

Note: The corn and soybean yields used in this analysis are above state averages because those areas targeted for wetlands are the most productive soils in the state.

within the basin. Table 1 shows the potential impacts on Illinois of solutions proposed by U.S. EPA. Cropland acres are used as a base for calculations instead of total acres because land in the Illinois is urban, farmland, or wooded. In those areas where the nitrogen load is the greatest, more than 90% of the land may be devoted to crop production.

Costs and Benefits of Controlling Hypoxia

The legislation that created the Task Force (PL 105-383) requires that the plan to address Gulf hypoxia include a description of the social and economic costs and benefits. Currently, the Action Plan does not include a description of the social and economic costs and benefits.

The Integrated Assessment states the following: "The benefits of a program to reduce nitrogen loads to the Gulf are difficult to quantify." (CENR 2000). The economic analysis (Doering et al. 1999) concluded that "... the direct measurable dollar benefits to Gulf fisheries of reducing nitrogen loads from the Mississippi River Basin are very limited at best."

According to Doering et al. (1999), "Social costs would also be incurred, such as dislocation in land use, agribusiness infrastructure, and farm communities. We can tell in some cases, and infer in others, where we might begin to incur unacceptable costs of this kind on the basis of historical shifts in crop production, land use, and input use. We did not estimate these costs." Also, the analysis does not discuss the impacts on local units of government in areas where large amounts of cropland are taken out of production.

In addition, neither the scientific reports nor the Integrated Assessment presents convincing evidence that excess nitrogen is a widespread problem affecting the aquatic resources within the Mississippi River basin. Although there are instances where nitrate concentrations exceed the drinking water standard in surface water sources for public water supplies, adequate evidence has not been presented to show that high nitrogen levels are affecting the goals of fishable and swimmable streams within the basin. If the water quality program in Illinois is to be directed by the state and address in-state priorities, excessive phosphorus and sediment should remain as the primary pollutants of concern in targeting state resources.

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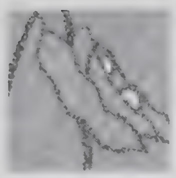


Ecologically-Based Water-Quality Criteria for Nutrients

David Pfeifer

Nutrient criteria are reported frequently as a cause of impairment of surface waters across the United States. In the Environmental Protection Agency's (EPA) 1996 National Water Quality Inventory, nutrients were identified as contributing to the impairment in 40% of the streams and 51% of the lakes reported as impaired. Under Section 303(c) of the Clean Water Act, states are required to develop criteria for pollutants that could cause or contribute to impairment of surface waters. In addition, development of total maximum daily loads (TMDLs) for impaired waters further emphasizes the need for nutrient criteria.

Development of surface water quality criteria for nutrients poses substantial technical challenges. Established methods (EPA) for deriving water quality criteria are based on measuring the toxic effects of individual pollutants in the laboratory and converting these data into criteria to protect specific uses of surface waters. These methods are not applicable to nutrients that exert their adverse impacts indirectly such as through excessive plant and algal growth, or reduced levels of dissolved oxygen, community composition, and aesthetics.

The technical difficulties associated with development of surface water quality criteria for nutrients necessitate a departure from standard methods of criteria development. The EPA's proposed approach relies on identifying appropriate background concentrations of nutrients as the basis for establishing water quality criteria. These values are based upon eco-regions and vary by water body type, with different criteria in each region of the country for rivers and streams, lakes and reservoirs, and wetlands and estuaries. To establish the appropriate background nutrient levels eco-region criteria are derived by pooling nutrient data for each type of water resource. These levels are used as the basis of criteria, in conjunction with other available information. The premise is that by setting the criteria at a level approximating unaffected background levels, any possible uses necessarily will be protected. The EPA's criteria recommendations will include both causal (total nitrogen and total phosphorus) and response elements (turbidity, chlorophyll *a*).

The EPA's program to develop recommendations for surface water quality criteria for nutrients is in its third year. The publication of recommendations is expected by the end of 2000 and states will be obliged to adopt nutrient criteria of their own. In developing their criteria, states may adopt directly the EPA's recommendations, adopt criteria derived from EPA's recommendations but adjust them to better reflect state-specific conditions, or adopt other scientifically defensible criteria. Criteria developed by states are subject to EPA review and approval, and the agency has the authority to promulgate Federal criteria for states that either fail to act or adopt inappropriate criteria.

Specialty Corn and Soybeans

Pete Fandel

The University of Illinois has been working on an Illinois Council on Food and Agricultural Research (C-FAR)-funded project entitled *Improving Farmer Incomes through Value-Added Agriculture* for the past 3 years. Part of this project has focused on on-farm research trials to evaluate the productivity and profitability of different value-added traits associated with different types of specialty corn and soybean.

During the 1999 growing season, on-farm trails were conducted at 19 locations in 11 counties in western and central Illinois to compare yields and expected economic returns from different specialty corn hybrids and soybean varieties. The objective was to compare the profitability of these specialty crops with elite conventional hybrids and varieties under the same conditions.

In 2000, the number of on-farm research and demonstration trials increased to 72 (33 for specialty corn and 39 for specialty soybean) across the state. Mike Roegge, Adams/Brown Extension Unit Educator in Crop Systems, was primarily responsible for organizing this research activity under the technical guidance of Emerson Nafziger, Extension Crop Production Specialist in the Department of Crop Sciences. Regional coordinators were Dennis Bowman (Crop Systems Educator in Champaign) for eastern Illinois; Robert Bellm (Crop Systems Educator in Edwardsville) for southern Illinois; Jim Morrison (Crop Systems Educator in Rockford) for northern Illinois; and Mike Roegge and Pete Fandel (Woodford Extension Unit Educator in Crop Systems) for western Illinois.

University of Illinois crop systems Extension staff from throughout the state identified farmers to participate in this on-farm research program, assisted them in getting the plots planted, and helped with data collection and sampling during harvest. I anticipate that the results from the on-farm research trials conducted during the past 2 years will help determine where certain specialty crops should be planted in Illinois. All of the research results from this project can be found at the Value project Web site at http://web.aces.uiuc.edu/value/.

Western Corn Rootworms in the 21st Century: New Research on an Old Problem

Joseph Spencer, Susan Ratcliffe, Scott Isard, Eli Levine, Christopher Pierce, and Silvia Rondon

In 1997, we initiated a study to monitor the statewide distribution of rotation-resistant western corn rootworms and other beetles (northern corn rootworms, southern corn rootworms, lady bird beetles, bean leaf beetle, and Japanese beetle) in soybean fields. We also began sampling for soybean diseases in counties throughout Illinois in 1999. The database from this study contains information about the spread and abundance of these and other potential insect vectors of plant disease. Western corn rootworm adults from these collections are being used for comparative biological and genetic studies; plant materials collected from the same fields provide information about the severity and distribution of bean pod mottle virus (BPMV) in Illinois. BPMV is a disease of soybean that causes the stems of infected plants to remain green after the plant is mature, resulting in problems with harvest. Plants infected with BPMV also are predisposed to other diseases that lower seed quality. This work compliments another study in which some of us are investigating the potential for adult western corn rootworms to transmit BPMV among soybean plants. In 1999, we discovered that some western corn rootworm beetles collected in soybean carried this virus. We currently are conducting BPMV transmission studies to determine whether western corn rootworms are capable of spreading this disease.

Studies of seasonal and diurnal movements of rotation-resistant western corn rootworms in and between corn and soybean fields have provided us with extensive behavioral data. During the past 4 years, data from malaise traps have shown a clear daily pattern of western corn rootworm immigration into and emigration from soybean fields. Sixty-five to 70% of western corn rootworm adults collected in soybean fields were female. Western corn rootworms are most abundant in the air during midmorning and immediately before dusk. Western corn rootworm flight is highly sensitive to weather conditions and is curtailed at high wind speeds and low air temperatures. The flight from corn to soybean fields is most pronounced during mid-morning, whereas adults fly from soybean to cornfields during the rest of the day. Beetle movement from corn to soybean also was monitored with vial traps in Champaign County (where rotation-resistant western corn rootworms are a problem) and near Monmouth, Perry, and DeKalb (nonproblem areas). Adults were abundant in Champaign County and scarce near Monmouth and Perry. We trapped moderate beetle numbers in soybean fields near DeKalb. Based upon these data, injury to first-year corn in northern Illinois could occur in the near future. Western corn rootworm movement in cornfields averages much less than 1 meter/hour. Male western corn rootworms seeking mates arrived at cages of unmated females at the rate of 1 male per 6.6 minutes. During the July mating period, we found no evidence for long distance (>10 m) male attraction to females. After mating, some female western corn rootworms leave cornfields and migrate at high elevations (≥8–10 m above the ground). Data from 3 years of collections from traps positioned on towers at 4 and 8 meters above a soybean field revealed that most long-distance movement of western corn rootworms occurs in late July and declines thereafter. The population of high-flying migratory western corn rootworms (8-meter level) is 75–85% female; migrating females are all mated, but not capable of laying eggs. Meteorological measurements taken at these heights in July and

August 2000 revealed that variations in abundance of western corn rootworms aloft depend on the stability of the local atmosphere.

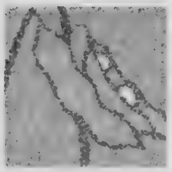
Laboratory bioassays have revealed significant differences in survival of adult western corn rootworms that have fed upon the foliage of different soybean lines, suggesting that we may be able to exploit such cultivars to reduce egg-laying in locations where these soybean lines are planted. In field studies, we are examining the role that planting dates and hybrid selection play in the selection of corn and soybean by females for egg-laying. Preliminary results indicate that late-planted corn is more attractive to gravid females than early-planted corn. We have monitored seasonal egg-laying in corn and soybean fields to determine peak egg-laying periods in on-farm research trials. We also have conducted field assays to determine egg-laying in a variety of crops (corn, soybean in 30-inch rows, soybeans in 7-inch rows, oats/wheat, and alfalfa). In 1998 and 1999, soil samples indicated that female western corn rootworms prefer to lay eggs in corn. However, a 2-year rotation of corn with crops other than soybean may not be a reliable management strategy because eggs can be found in the other cropping systems.

In 2000, we solicited volunteers in 50 counties to monitor soybean fields with Pherocon® AM sticky traps to predict the need for a soil insecticide in first-year corn in 2001. More than 29,000 free sticky traps were distributed to participants in the program, and many have forwarded scouting data for inclusion in the Western Corn Rootworm Database. A similar program was conducted during 1998 and 1999 and followed up each successive year with root ratings from cornfields that had been planted after soybean. As a result of the On-Farm Root Rating Program in 1999 and 2000, we established a new threshold of 5 to 10 beetles per trap per day to predict potential economic damage caused by corn rootworm larvae.

Troubleshooting Field Crop Problems

Suzanne Bissonnette and Dave Feltes

Each season has its share of difficult field problems to solve for clientele. Whether it is an environmental problem, a new pest outbreak, a new pest management technique that just isn't responding well, or a combination of many factors, producers need answers. A good working knowledge of pest identification and diagnosis is only the beginning of problem solving. A systematic approach to troubleshooting difficult field problems is presented in this workshop. Field examples from the 2000 season are presented and discussed. Draw from your own field experiences to see whether you can diagnose these challenging field-crop injury problems. Examples of problems addressed in this session include injury caused by insects, diseases, herbicides, and abiotic factors. Resolutions for these problems also are addressed.

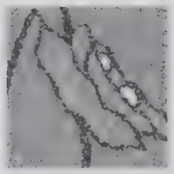


Sudden Death Syndrome of Soybean

Darin Eastburn and Loretta Ortiz-Ribbing

Sudden death syndrome (SDS) is a disease of soybean caused by the soilborne fungus *Fusarium solani* f.sp. *glycines.* The fungus infects the soybean plant through the root system, causing rotting of the roots and crown and a discoloration of the vascular system in the lower stem. Although the fungus does not move into the leaves, symptoms develop on the leaves as a result of infection of the roots. Yellowing and browning of the areas between the leaf veins are foliar symptoms characteristic of SDS. So far, methods for adequately managing SDS have not been identified. One of the most promising strategies for controlling this disease seems to be the use of disease-resistant varieties. Although none of the varieties tested thus far are immune to SDS, varying levels of resistance and susceptibility among commercially available soybean varieties have been observed. Much of the work on resistance to SDS has focused on resistance to the development of foliar symptoms. However, less attention has been paid to the role of the soybean root system in resistance, which is interesting given that the pathogen infects and colonizes the root system. Root systems of different soybean varieties may differ in their ability to resists colonization or to compensate for roots lost to infection. The time at which soybean roots become infected in the field, and the effects of differing tillage regimes on root growth, root system colonization, and disease development also are not well understood.

Research currently is being conducted at the University of Illinois to evaluate the importance of the root system in disease expression. The objectives of this research are 1) to determine whether root characteristics, such as root system architecture, root surface area, and time of colonization, are involved in the observed resistance of certain soybean varieties to SDS; and 2) to evaluate the effects of deep tillage and soil moisture on the development of SDS. The root parameters that we are measuring in these studies included root density, time of colonization, disease severity, and yield. These parameters are being evaluated through various methods, including the use of digital imaging. The preliminary results of this research, along with results of the statewide SDS survey and other research projects, are presented in this workshop. In addition, plant specimens are available to help participants learn to distinguish SDS from other diseases that cause similar foliar symptoms. Correct identification of SDS symptoms is important to the effectiveness of disease management strategies.



Soybean Cyst Nematode (SCN) Biology, Sampling, and Resistance

Dale Edwards and Brian Diers

Introduction

Soybean cyst nematode (SCN) is the most serious soybean pest in Illinois and other soybean-producing states. SCN has been confirmed in most counties in Illinois since it was found first in Pulaski County in 1959. An awareness of the problem is the first step in managing this pest.

SCN Biology and Life Cycle

Soybeans are infected by the second-stage juvenile, a microscopic (0.02 inch long), colorless worm. Juveniles penetrate the soybean by puncturing the roots with a spearlike feeding structure, the stylet. They invade the root, and then migrate toward food-conducting tissues, where they feed and mature. Feeding alters the internal root structure, thereby interfering with normal root functions and ultimately causing plant damage. In approximately 3 weeks under optimum conditions (soil temperatures at 80– 84°F or 27–29°C), egg-bearing females develop from the juveniles. At 90°F (32°C) and higher temperatures, nematode development is slower and numbers reaching maturity are reduced.

The females enlarge greatly as they develop, becoming lemon shaped. They break through the root surface while remaining attached to the root by the head. The females lay eggs in a jellylike mass attached to their posterior end and retain approximately two-thirds of the eggs within their swollen bodies. If an infected plant is dug at this stage, the attached females can be seen with the unaided eye as shiny, white, spherical bodies about the size of the period at the end of this sentence. This stage is the so-called white female stage.

After death, the white female stage changes from yellow to brown, the brown cyst stage. By the time brown cysts are formed, the cyst (the altered female body wall) has become a protective structure containing up to 400 eggs. The cyst wall protects the eggs from drying, chemical action, and some parasites. For these reasons, the brown cyst stage is best suited for the spread of the nematode to new areas. The nematodes can complete as many as four generations in a single growing season. Thus, if one cyst containing 400 eggs is introduced into a soybean field in the spring, several thousand cysts could be produced in one growing season. Thus, the introduction of a single cyst into a field represents a potentially high nematode population that could cause noticeable damage within a few years.

A system for distinguishing among four races (designated 1, 2, 3, and 4) of SCN, by using four soybean differentials and a susceptible check, has been in use since 1979. In 1988, a new system of designating races increased the number of potential races to 16. Races are characterized by their ability to reproduce on certain soybean varieties. Race 3 is found most frequently in Illinois, followed by race 1. Races 2, 4, 5, 6, 8, and 9 are known to occur in Illinois but do not seem to be widely distributed.

Sampling for SCN

Identifying the problem is the first step in controlling SCN. Soybean producers should be familiar with SCN symptoms and should suspect SCN where

yields are reduced without explanation. The best way to determine whether SCN is present and to determine population densities is to collect a soil sample and submit it for analysis. A preferred time to sample is in the fall, after harvest, so that analysis for SCN densities provides timely information for planning the next growing season. However, samples may be collected any time during the growing season to confirm the presence of SCN.

Soil samples should be collected to a depth of 6–8 inches. By using a zigzag pattern, collect 12 to 24 soil cores with a soil probe. Place cores from each 20-acre set into a bucket, mix thoroughly, and submit approximately 1 pint in a plastic bag to a soil-testing laboratory. The University of Illinois Plant Clinic (1401 W. St. Mary's Rd., Urbana, IL 61802) conducts assays for SCN. Also, there are several private laboratories in Illinois that are capable of processing soil samples. For a list of these laboratories, contact the extension nematologist at 217-244-2011. All laboratories charge a fee for processing samples (refer to Report on Plant Diseases #1107, Predictive Soil Sampling and Analysis Procedure for the Soybean Cyst Nematode).

Control: An Integrated Approach

Ideal programs to manage SCN infestations have successfully integrated detection through scouting and sampling procedures and crop rotations with nonhost crops and SCN-resistant soybean varieties. Maintaining proper soil fertility and pH, managing other soybean diseases and pests, and proper planting methods also help to keep plants vigorous and better able to buffer the effects of SCN. The most effective management system has been, and will continue to be, an integration of approaches.

The success story of managing SCN has been the use of resistant varieties. Three decades ago, only a small number of SCN-resistant varieties were available. Today, through the efforts of public and private soybean breeders, this list has expanded to approximately 700 lines adaptable to Illinois growing conditions. Since 1977, the University of Illinois, in cooperation with the United States Department of Agriculture, has released 22 resistant varieties ranging from maturity group I through IV. Newer releases have improved yield potential and the ability to resist up to five races of the nematode.

Development of SCN-Resistant Varieties

Most SCN-resistant varieties available in Illinois have their resistance derived from PI 88788, a plant introduction collected in China in 1930. PI 88788 is an important resistance source primarily because it has produced varieties with higher yield than other sources. Many important varieties with PI 88788 resistance were developed at the University of Illinois, including Fayette and Jack, which can be found in the pedigrees of most private and public SCN-resistant varieties in Illinois.

Soybean cyst nematode currently is controlled in most Illinois fields with the PI 88788 source of resistance. However, research has shown that nematode populations in fields can evolve and eventually overcome resistance genes. For example, PI 88788 provides resistance to SCN races 3 and 14 but only partial resistance to race 1. In some fields where the PI 88788 source has been used extensively, SCN race 1 is becoming more common. The evolving nature of SCN highlights the importance of developing varieties with new resistance genes. Researchers both at universities and private companies currently are involved in developing new varieties by using different resistance sources that can control other races of SCN.

Understanding Herbicide Modes of Action: Invaluable in Diagnosing Herbicide Injury Symptoms

Dean Riechers and Lawrence Steckel

Herbicide mode of action may be defined as how a herbicide kills a plant. A working knowledge of herbicide mode of action can be beneficial when attempting to diagnose herbicide injury in the field. Ideally, a herbicide should provide good weed control without adverse effects on the crop. Many of the herbicides used today are very active on weeds at extremely low rates, but they also may injure the crop, especially under environmental conditions that lead to plant stress. In addition, herbicide injury may result from misapplication (sprayer overlap) or unintended applications, such as carryover, tank contamination, or off-target drift.

Mode of Action versus Translocation: When versus Where Herbicide Injury Develops

Herbicide mode of action and translocation are two important factors to keep in mind when diagnosing herbicide injury. Knowledge of herbicide mode of action aids in determining how fast the injury symptoms should develop (*when* you see the injury), and knowledge of translocation patterns helps in determining *where* the injury symptoms should appear on the plant.

Contact burners, such as paraquat (Gramoxone), Blazer, Cobra, Flexstar, and Buctril, kill plants very quickly, but they only kill the plant foliage that comes in contact with the herbicide spray solution, and little if any translocation to the roots occurs. The injury symptoms associated with contact burner herbicides (rapid browning and eventual necrosis of treated plant tissues) develop so quickly that the herbicide cannot move out of the treated plant foliage to the roots.

In contrast to the contact burners, amino acid and fatty acid biosynthesis inhibitors are considered to be **systemic** herbicides. Examples of amino acid biosynthesis inhibitors (glyphosate products, acetolactate synthase [ALS]-inhibitors) include Roundup, Touchdown, Classic, Accent, FirstRate, and Pursuit. Examples of fatty acid biosynthesis inhibitors (or POST-grass herbicides) include Select, Poast Plus, and Assure II. These herbicides show injury symptoms that develop first on the newer leaves and meristems, and develop much more slowly than the contact burners, so translocation of the herbicide to the roots can occur. Systemic herbicides are thus excellent for controlling perennial weeds. The plant growth regulator (PGR) herbicides, such as 2,4-D, Banvel, Clarity, Distinct, and Stinger, also are systemic herbicides that cause epinasty (stem-twisting) on most broadleaf weeds. These herbicides also are excellent for controlling perennial broadleaf weed species. Most grasses, including corn and wheat, are tolerant to PGR herbicides; however, very low amounts of PGR herbicides that are unintentionally applied (usually as spray drift or tank contamination) to soybean can result in injury. Symptoms of PGR injury in soybean include leaf strapping (leaf veins appear parallel), crinkling, or cupping on young, newly expanding leaves.

Soil-applied triazines, such as Aatrex and Sencor, are also systemic herbicides that move throughout the plant, but translocation is limited to the transpira-

tion stream (xylem), so only older, mature leaves that are transpiring the most receive the triazine herbicide. Typical triazine injury symptoms include yellowing and eventual necrosis of the older leaves, especially around the leaf margins. POST-applied atrazine has injury symptoms that appear more like the contact burners, and little translocation out of the foliage occurs.

Under certain environmental conditions, soil applications of Balance in corn and carryover injury from Command can lead to corn seedlings that appear white, or bleached. This injury can be confused with spray drift injury from Roundup or Touchdown POST applications. Because Roundup and Touchdown are systemic herbicides, small amounts of spray drift onto corn leaves can kill the entire plant.

The Need for Herbicide Safeners

Under certain environmental conditions, such as cool, wet weather in the spring, crops can be injured by herbicides. Herbicide safeners often are included with soil-applied herbicides, such as the acetamides (Dual II Magnum, Harness, Surpass) and thiocarbamates (Eradicane, Sutan +) to decrease the occurrence of corn injury under these conditions. Wet conditions increase the availability of the herbicide in the soil, which is good for weed control, but they also can increase the amount of herbicide taken up by the corn seedling. Under cool conditions, metabolism of the herbicide in the corn plant is slower, so injury such as buggy-whipping and underground leaf unfurling can occur. Herbicide safeners help to prevent such injury by increasing the ability of the corn seedling to rapidly metabolize the herbicide to a nontoxic form, even under cool, wet soil conditions, thereby allowing the corn seedling to emerge from the soil without injury.

Secondary or Primary Insects? Will Grape Colaspis and Companions Change Our Management Strategies in Corn?

Kevin Steffey, Mike Gray, and John Shaw

To respond to requests for more information about secondary insect pests of corn, we published an article in the *Proceedings of the 2000 Illinois Crop Protection Technology Conference* (Steffey and Gray 2000). Wireworms, white grubs, grape colaspis, and southern corn leaf beetles were featured in the article because infestations by these pests had been prevalent in both 1998 and 1999. We had searched all issues of two scientific journals, the *Journal of Economic Entomology* and *Environmental Entomology*, to find articles about secondary insect pests of corn that had been published during the past 10 years. Unfortunately, few such articles were published in the two journals during 1990–1999, so we had little new information to offer. Nevertheless, we suggested strategies and tactics for managing secondary insect pests of corn, with the caveat that more research is necessary to answer important questions about these pests.

In 2000, the number and intensity of infestations of cornfields by grape colaspis, southern corn leaf beetle, and white grubs far exceeded infestations in 1999. Infestations of grape colaspis and southern corn leaf beetle in 2000 were widespread in east central, central, western, and southern Illinois; significant infestations also occurred in other midwestern states, especially Iowa and Missouri. The numbers of reports of injury to corn seedlings caused by white grubs also increased from 1999 to 2000; annual white grubs (especially Japanese beetle grubs) were blamed for much of the damage. To add insult to injury, wireworms were prevalent again.

In our article (Steffey and Gray 2000), we speculated that grape colaspis and other "minor" insect pests may become more commonplace if corn producers in Illinois continue to plant early and if mild winters persist. The reoccurrence of several secondary insect pests of corn in 2000 lends some credence to our speculation because the 1999–2000 winter was mild and corn producers planted relatively early again in 2000. After 3–4 years of battling with so-called "secondary insect pests of corn," many people associated with agriculture wonder when we will raise their status to "primary pests."

Although nothing new pertaining to secondary insect pests of corn was published in the scientific literature within the past year, some recently conducted field research should improve our knowledge base slightly. In this article, we describe the situation that occurred in 2000, offer data from some insecticide efficacy studies, discuss some new control options, and speculate about the prospects for secondary insect pests of corn in 2001.

Overview of 2000, and a Couple of Observations from the 1920s

By late April, we began to receive reports of infestations of seedling corn by southern corn leaf beetles, white grubs, and wireworms. In many fields, plant populations had been reduced sufficiently and the producers decided to replant. The insects continued to cause significant damage throughout May, and some of the replanted fields had to be replanted a second time. This level of expenditure for seed, not to mention the cost for any insecticides applied, is enough in some people's minds to elevate the pests' status to primary.

Grape colaspis joined the fray in early May and became the most notorious insect pest of corn in the central one-third of Illinois for the next 6 weeks. Most of the cornfields infested had been planted to soybean in 1999. Some fields of soybean in 2000 that had been planted to corn in 1999 also were infested with grape colaspis. In the Entomological Society of America's *Handbook of Corn Insects* (Steffey et al. 1999), I wrote this about grape colaspis: "The grape colaspis is a sporadic pest most often found in corn planted after red clover or mammoth clover, and occasionally in corn planted after sweet clover, alfalfa, or soybeans." Information to support that quote had been extracted from some rather old scientific literature. Apparently, we need to reconsider the statement about "occasionally in corn planted after ... soybeans." Very little acreage is currently devoted to clover production in Illinois, so that preferred host is no longer readily available. It is possible that the grape colaspis has adapted to modern corn–soybean rotation to survive.

An article published by Bigger in 1931 includes some interesting observations about grape colaspis in Illinois. He indicated that "the most severe damage [caused by grape colaspis larvae] occurred in corn planted on land where red clover had been plowed under." However, he also observed that some reductions in plant populations in corn that had been planted after soybean. Nevertheless, he offered this suggestion for consideration: "The use of sweet clover or soybeans to replace red clover as a soil-building crop would greatly reduce the necessity of supplementary control measures." Interesting.

Bigger (1931) also conducted a 3-year study (mid-1920s) of the effects of timing of tillage on the occurrence of grape colaspis. He reported that "the fall and early-spring plowings showed the least numbers of larvae present and the highest yields of corn on the plots." Damage was consistently worse in plots and fields that had been plowed late in the spring just before the corn was planted. Can we use this type of information for our advantage? We certainly should keep it in mind when we visit colaspis-injured fields in the future.

Now, back to 2000. The southern corn leaf beetle was in full "outbreak mode" during the first half of May. Although the outbreak of southern corn leaf beetles did not rival the severity of outbreaks of other arthropod pests in our recent past (e.g., twospotted spider mite in 1988), the frequency of occurrence of this poorly understood pest captured attention. Similar to reports of infestations in 1999, southern corn leaf beetles were observed more frequently in no-till and reduced-till fields than in "conventionally" tilled fields in 2000.

Efficacy of Insecticides against Secondary Insect Pests of Corn

During 2000, we were able to accumulate some data regarding the effectiveness of different products for control of southern corn leaf beetles and wireworms, and we generated some of our own data regarding insecticide efficacy for grape colaspis and white grubs. Armon Keaster, retired Professor of Entomology at the University of Missouri, Columbia, supplied data for control of wireworms with different insecticides. Efficacy data for soil insecticides are provided in Table 1; efficacy data for seed

Table 1 ■ Efficacy (expressed as percentage of healthy plants) of soil insecticides against wireworms, 1991–1998 (supplied by Armon Keaster, University of Missouri, Columbia).

Product	Rate[1]	Placement[2]	1991	1992	1993	1994	1995	1996	1997	1998	Average
Aztec 2.1G	6.7	In furrow	75	87	—	83	80	69	78	88	80
Counter 15G	8.0	In furrow	79	82	85	77	88	70	79	—	80
Counter CR	6.0	In furrow	51	81	71	66	88	68	81	81	73
Force 3G	4.0	In furrow	—	—	80	80	87	67	82	87	81
Fortress 5G	3.0	In furrow	—	—	—	—	76	72	77	84	77
Furadan 4F	1.8	In furrow	—	—	85	83	—	76	83	91	83
Lorsban 15G	8.0	In furrow	—	78	73	72	79	68	69	—	73
Regent 4SC	0.24	Through microtubes	—	—	—	—	—	—	66	86	76
Thimet 20G	6.0	7-inch band	87	74	76	69	81	68	76	85	77
Untreated control	—	—	7	62	45	58	71	64	49	76	54

[1] Ounces of product per 1,000 feet of row.

[2] All products applied at planting time.

Table 2 ■ Efficacy (expressed as percentage of healthy plants) of seed treatments against wireworms, 1993–1998 (supplied by Armon Keaster, University of Missouri, Columbia).

Product	Rate[1]	1993	1994	1995	1996	1997	1998	Average
Kernel Guard	3.6	75	88	—	—	70	86	80
Germate Plus	3.6	—	—	89	92	76	82	85
Kernel Guard Supreme	3.6	—	—	—	—	61	83	72
Untreated control	—	41	58	86	81	54	82	67

[1] Ounces of product per 1,000 feet of row.

treatments are shown in Table 2. Generally, application of soil insecticides or the use of insecticide-treated seed provided protection against attack by wireworms. Differences in efficacy of the soil insecticides tested are most apparent within years, although the differences are relatively slight on average. The efficacy of seed treatments also varied among years, with Kernel Guard Supreme providing the least amount of protection against attack by wireworms.

Dave Thomas, Field Development Representative with Zeneca Ag Products, provided a copy of some efficacy data generated in 1998 by entomologists and Extension personnel at Kansas State University, Manhattan. The field was located near Troy, KS, not too far from St. Joseph, MO. The products tested, their rates of application, and evaluations of efficacy are shown in Table 3. The total number of living adults in the untreated plot was significantly higher than the numbers of living adults in all plots treated with insecticides. The numbers of living adults in plots treated with Ambush and in plots treated with Warrior at 0.02 lb AI/acre were significantly higher than the numbers of living adults in all other insecticide-treated plots. Baythroid applied at both rates, Warrior applied at 0.03 lb AI/acre, Lorsban, and Pounce and provided equivalent control. However, Baythroid is not registered for use on corn. In their notes accompanying the data, the following is attributed to Randy Higgins, Extension Entomologist at Kansas State University: "Higgins believes that it is possible that the insect may have been causing damage for years with the damage mistaken for black cutworms during years when it had been a problem. Damage strongly resembles severe cutworm injury." Randy may be right, which further emphasizes the need for accurate diagnosis before insect control is initiated.

Results from our insecticide efficacy trial for control of grape colaspis and annual white grubs are presented in Table 4. The experimental design was a randomized complete block with four replications. For each replicate by treatment combination, we dug a trench approximately 1 meter in length and 15

Table 3 ■ Efficacy of insecticides against southern corn leaf beetle, Troy, KS, 1998 (supplied by Randy Higgins, Kansas State University, Manhattan).

Product	Rate (lb AI/acre)	Total no. of adults per four plants[1,2]	Total no. of live adults per four plants[1,2]	Total no. of dead adults per four plants[1,2]	Plant damage (0 to 4 scale)[1–3]
Untreated control	—	8.00a	8.00a	0.00a	1.80a
Lorsban 4E	1.0	1.67c	1.00c	0.67a	0.90a
Pounce 3.2EC	0.1	2.33c	1.67c	0.67a	2.10a
Ambush 2E	0.1	5.00b	4.33b	0.67a	1.60a
Warrior T	0.02	4.33b	4.33b	0.00a	1.80a
Warrior T	0.03	2.33c	2.33c	0.00a	1.00a
Baythroid 2E	0.025	1.33c	1.33c	0.00a	1.90a
Baythroid 2E	0.031	2.33c	2.00c	0.33a	1.10a

[1] Evaluations made 4 days after treatment with insecticides.
[2] Numbers in columns followed by different letters are significantly different at the 5% level; ANOVA; protected LSD.
[3] Plant-damage rating scale not explained.

centimeters (6 inches) in depth. The numbers of living corn seedlings per meter were recorded. All soil from the trench was examined for grape colaspis and white grub larvae, and the numbers of insects found were recorded. This process was very time-consuming because of the abundance and small size of grape colaspis larvae. The plants in many of the plots were stunted and purple, symptoms of injury attributable to both grape colaspis and white grub larvae. We did not attempt to distinguish which insects caused the injury.

We observed considerable variation in numbers of live plants, grape colaspis, and white grubs among the plots. Only plots treated with Regent 4SC had significantly more live plants (8.0 plants per meter) than in the untreated control (4.13 plants per meter). The numbers of grape colaspis larvae per meter of row in insecticide-treated plots were not significantly different from the number of grape colaspis larvae in the untreated control. This observation compares well with past testimonials regarding lack of performance of soil insecticides against grape colaspis. Many products significantly reduced the density of white grubs; however, grubs were present in all plots.

One final note about this trial is in order. No soil insecticides currently are registered for control of grape colaspis larvae. Results from this experiment should not be used to justify the application of a product for grape colaspis control.

Table 4 ■ Insecticide efficacy trial results for grape colaspis and white grubs, Tallula, IL, May 23–24, 2000. (Originally published in its entirety in issue No. 11, June 9, 2000, of the *Pest Management & Crop Development Bulletin*, University of Illinois Extension, Urbana-Champaign.)

Insecticide[1]	Formulation	Rate	Application	No. live[2] plants	No. live[2] grape colaspis	No. live[2] white grubs
Aztec	2.1BD	6.7 oz/1,000 row ft	Band	6.25abc	4.00b	2.25bc
Capture	2EC	0.04 lb AI/acre	Furrow	5.00abc	9.00b	1.50bc
Capture	2EC	0.08 lb AI/acre	Furrow	4.00bcd	6.50b	1.75bc
Counter	20CR	6 oz/1,000 row ft	Band	6.00abc	6.75b	2.25bc
Counter	20CR	6 oz/1,000 row ft	Furrow	3.50cd	3.50b	1.75bc
Force	3G	5 oz/1,000 row ft	Furrow	5.25abc	6.25b	4.50abc
Force	3G	4 oz/1,000 row ft	Band	4.25bcd	9.25b	2.75bc
Force 2829	30CS	0.12 lb AI/acre	Microtube at planting	5.75abc	2.75b	3.25abc
Force 2829	30CS	0.12 lb AI/acre	Band	7.00ab	12.25ab	3.50abc
Fortress	5G	0.16 lb AI/acre	Furrow	5.00abc	3.25b	0.50c
Gaucho	Seed treatment	0.5 mg AI/kernel	Seed treatment	5.25abc	8.25b	3.00abc
Gaucho	Seed treatment	1.35 mg AI/kernel	Seed treatment	4.75bc	10.00b	3.00abc
Lorsban	15G	8 oz/1,000 row ft	Band	1.50d	7.25b	3.25abc
Lorsban	15G	12 oz/1,000 row ft	Band	5.00abc	5.00b	1.75bc
Maxim XL	2.7 FS	0.06 oz AI/cwt	Seed treatment	4.25bcd	3.75b	1.50bc
Maxim XL + Adage	2.7 FS and 5 FS	0.06 oz. AI/cwt and 0.8 oz AI/cwt	Seed treatment	7.25ab	20.75a	4.25abc
Maxim XL + Kernel Guard Supreme	2.7 FS and 24.4 DS	0.06 oz AI/cwt and 1.8 oz AI/cwt	Seed treatment	4.00bcd	7.50b	5.25ab
ProShield	Seed treatment		Seed treatment	6.25abc	8.50b	1.25bc
Regent	4SC	0.13 lb AI/acre	Microtube at planting	8.00a	6.25b	2.50bc
Warrior T	1CS	0.03 lb AI/acre	Band	5.50abc	10.75b	4.25abc
Untreated control	—	—	—	4.13bcd	12.50ab	6.75a

[1] Insecticides were applied as seed treatments or as banded or in-furrow planting-time treatments on May 3, 2000. Plots were evaluated on May 23 and 24, 2000.

[2] Numbers of live plants, grape colaspis larvae, and annual white grubs were determined from a 1-meter trench (15 centimeters [6 inches] in depth) in each replicate by treatment combination. Means followed by the same letter do not significantly differ ($P = 0.05$, Duncan's New Multiple Range Test).

New Control Options

Before 2000, no insecticides were labeled for control of southern corn leaf beetle. In response to recurring problems with this troublesome pest, two companies added southern corn leaf beetle to some insecticide labels in 2000.

Capture 2EC (FMC Corporation) is labeled for control of southern corn leaf beetles in corn. The recommended rate of application is 2.1–6.4 ounces per acre. The label indicates that Capture 2EC should be applied in a minimum of 10 gallons of finished spray per acre with ground equipment. However, some people with experience with the product in southern Missouri suggested that 15 gallons per acre provides better results.

FMC Corporation also issued a Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) Section 2(ee) label for Furadan 4F for control of southern corn leaf beetles in corn. Zeneca Ag Products also issued a FIFRA Section 2(ee) label for Warrior T for **suppression** of southern corn leaf beetles in corn. Section 2(ee) of FIFRA allows companies to add insects to pesticide labels as long as the pest occurs in a crop for which the pesticide is registered and application rate does not exceed the maximum labeled rate. The recommendation must be in the possession of the user at the time of pesticide application.

Furadan 4F can be applied at 1 pint per acre for control of southern corn leaf beetles in corn. The label states: "Apply in sufficient water for thorough coverage using a minimum of 3 gallons of finished spray per acre with air equipment or 15 gallons of finished spray per acre with ground equipment. Do not use this product through any type of irrigation system."

Warrior T can be applied at 3.84 ounces per acre for control of southern corn leaf beetles in corn. The label states, in bold print: "**May be applied through chemigation equipment. Apply in a minimum of 2 gallons per acre by air or 10 gallons per acre by ground. When pest populations are high, 5–10 gallons per acre by air or 20 gallons per acre by ground and *higher use rates are recommended* (my italics).** We italicized the latter portion of the previous sentence because only one rate is listed on the label. Using higher-than-labeled rates of application is not legal.

The other new option for control of some secondary insect pests of corn is the use of recently labeled insecticidal seed treatments. ProShield Technology with Force ST (from Novartis Seeds/Zeneca) and Gaucho and Prescribe (from Gustafson) were registered for control of several soil insect pests of corn in 1999–2000. ProShield is labeled for control of white grubs and wireworms, as well as corn rootworms, cutworms, and seedcorn maggot. The active ingredient of ProShield (tefluthrin) is effective against both white grubs and wireworms when applied as Force 3G, a granular soil insecticide. Very little data regarding the efficacy of ProShield against white grubs and wireworms exist. However, we anticipate that its efficacy against wireworms should be good. The jury is still out on the efficacy of ProShield against white grubs, insects that do not feed directly on the seed.

Gaucho and Prescribe are labeled for control of seedcorn maggot and wireworms, as well as several other insect pests of corn. The active ingredient is imidacloprid, which is the active ingredient for several other insecticide trade names registered for use on many crops. Imidacloprid is systemic and has provided excellent control of insects, especially of insects with piercing-sucking mouthparts, in crops other than corn. However, efficacy data for control of wireworms with Gaucho- and Prescribe-treated corn seeds are not readily available. Because wireworms attack corn seeds and the stems of seedling corn, we anticipate that the efficacy of Gaucho and Prescribe against wireworms should be good.

Prospects for Secondary Insect Pests of Corn in 2001

The most difficult challenge associated with trying to manage secondary insect pests of corn is our inability to forecast their occurrence accurately. Old information indicates that the sequence of crops within a field can help us forecast the occurrence of certain soil insect pests. However, the prevalence of the corn–soybean rotation in Illinois precludes us from using knowledge about the sequence of crops to our advantage. Many people have offered testimonials that secondary insect pests of corn occur more often in no-till and reduced-till fields than in "conventionally" tilled fields. However, conservation tillage is practiced widely, and secondary insect

pests of corn do not occur in all no-till and reduced-till fields. In addition, some conventionally tilled fields also harbor infestations of grape colaspis, white grubs, and wireworms. So our ability to forecast is compromised again.

Sampling tools that would help us anticipate infestations of secondary insect pests are nonexistent, poorly tested, or not widely used. Solar bait stations are excellent tools for sampling for wireworms, but few people bother to establish them, even in high-risk fields. Yellow sticky traps have shown some promise for sampling for grape colaspis adults, but we have not been able to correlate numbers of adults on traps with levels of injury to seedlings the following year. Sampling for white grubs is labor-intensive and not practiced, and sampling for southern corn leaf beetle has not been broached.

We don't like to keep falling back on our speculations about mild winters and early corn planting and their effects on secondary insect pests of corn, but it's all we have at the moment. Verification or negation of our "theory" depends entirely on the weather and our ability to initiate some research projects.

It is possible that secondary insect pests will continue to challenge corn producers in the foreseeable future. Therefore, we recommend that people who scout cornfields and diagnose pest problems every year should have reasonably up-to-date references. Steffey and Gray (2000) described current knowledge and gaps (late in 1999) about billbugs, grape colaspis, southern corn leaf beetle, stink bugs, white grubs, and wireworms. The aforementioned *Handbook of Corn Insects* (Steffey et al. 1999) includes sections devoted to each of these secondary insect pests of corn, as well as excellent photos of the pests (courtesy of Marlin Rice, Extension Entomologist, Iowa State University), dichotomous keys for insect identification, and diagnosis of plant injury. Each insect-specific section includes information associated with the following subheads: origin and distribution, description, pest status, injury, life history, and management. At the very least, accumulating a library of resources, albeit a small library, is a first step toward successful management of secondary insect pests of corn.

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